Mechanical Design of CEPC Vertex Detector

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Feature and challenge

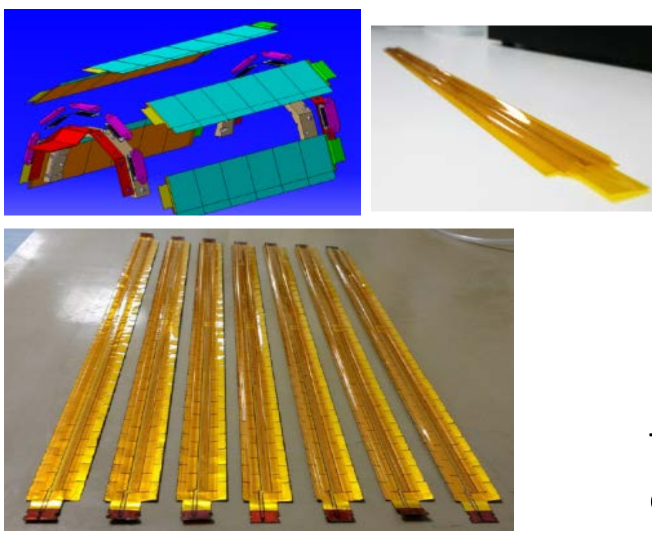
CEPC vertex detector (VTXD) features

- ✓ Low material budget - 0.15% X/X_0 for a single layer
- ✓ High spatial resolution 3~ 5 μm
- ✓ Air cooling

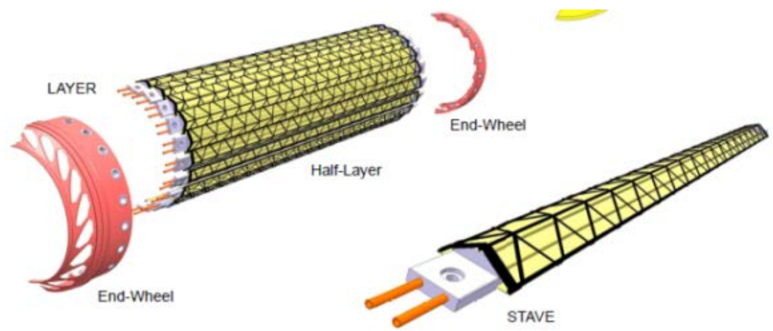
Challenges to the mechanical design

- Ultra-light support with robust mechanical performance

Mu3e (0.1% X/X_0)



Alice ITS Upgrade(0.3% X/X_0)

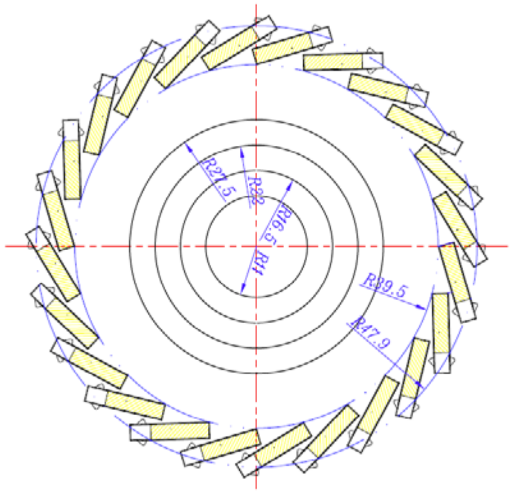


These two experiments both have silicon sensors on one side of the support.

Layout of the VTXD

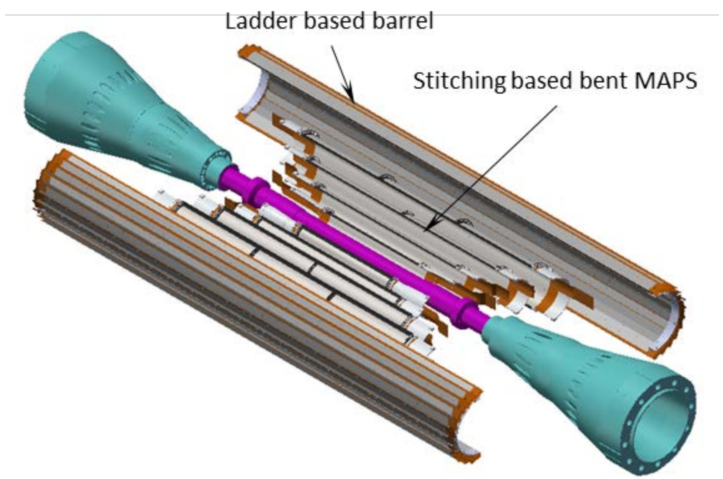
Baseline design

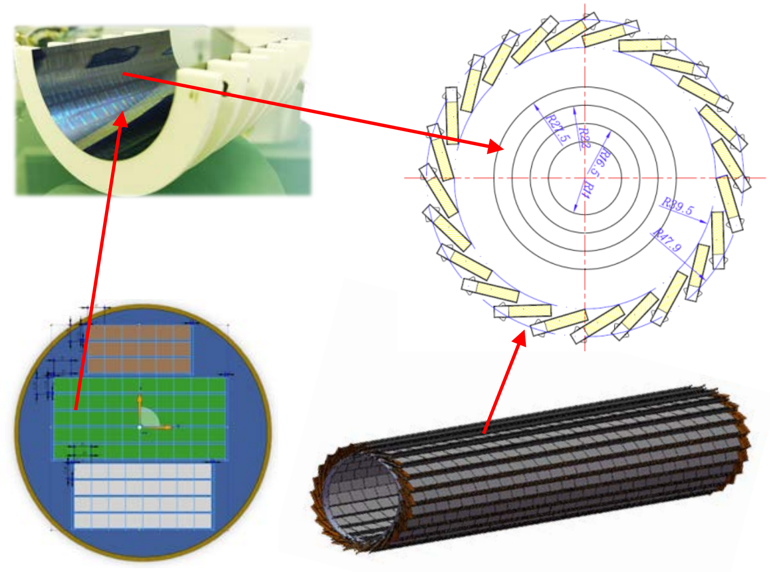
- 6 layers detector with acceptance coverage cosθ=0.99
- Inner four layers
  - ✓ Stitching tech based bent MAPS (*Monolithic Active Pixel Sensor*) cylinder
  - ✓ Low material budget per layer
- Outer two layers:
  - ✓ Flat MAPS based double-sided ladder (overlapped deployment)
  - ✓ No dead area

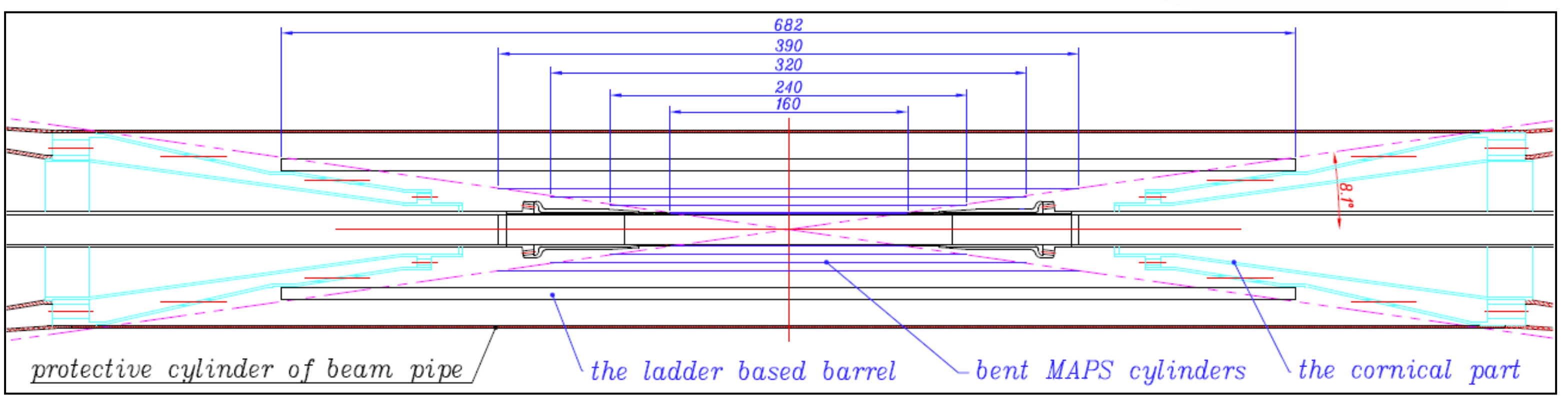


layer	Radius(mm)	Length(mm)
layer1	11	160
layer2	16.5	240
layer3	22	320
layer4	27.5	390
layer5/6	39.5-47.9	668

General structure of the VTXD



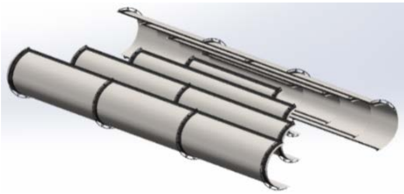




Stitching-based bent MAPS cylinders

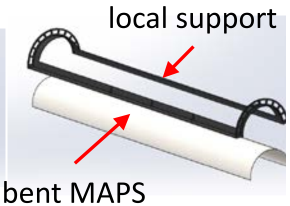
The 4 layers of bent MAPS cylinders

- Each formed by two half cylinders
- half cylinder assembled the by MAPS and local support
- one bent MAPS for layer1, two pieces connected in Z direction for Layer2~layer4
- Wafer t= 40 µm, local CFRP support t=0.12~0.15 mm

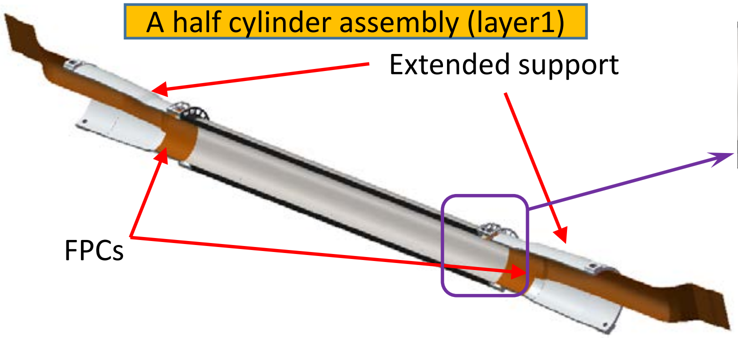


layer	Radius (mm)	Length (mm)	CFRP Equivalent thickness (mm)
layer1	11	160	0.057
layer2	16.5	240	0.034
layer3	22	320	0.032
layer4	27.5	390	0.04

The inner cylinder



A half cylinder assembly (layer1)

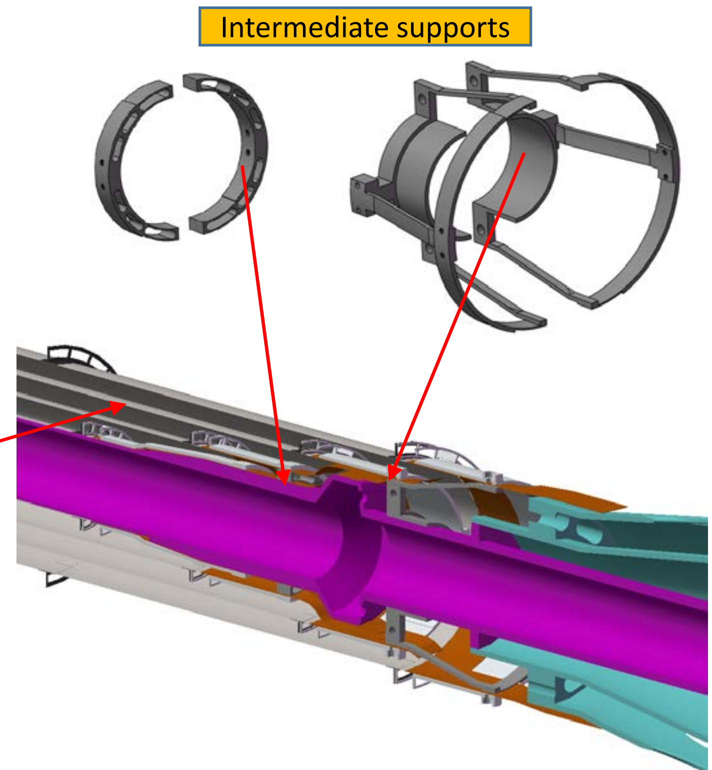


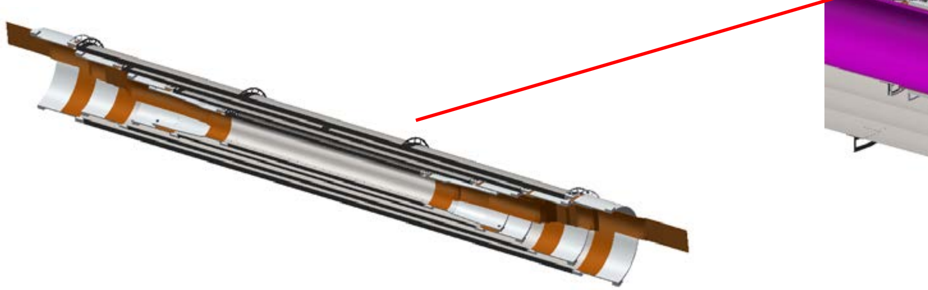
The half cylinder assembly (integration of the half cylinder, its extended support and FPCs)

- ➢ FPCs (flex printed circuit) connect to the ends of the bent MAPS by wire bonding
- ➢ The extended support assembled with the local support of the half cylinder to constraint the ends of FPCs and protect the wire bonds

The bent MAPS cylinders installation

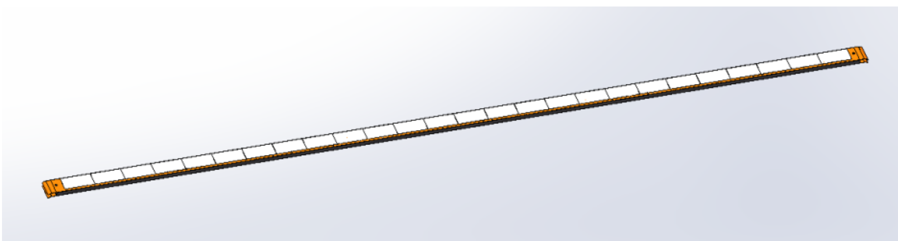
- Each cylinder assembly is independent to others and mounted separately, driven by the need of assembling and wire bonding for the half cylinder assembly.
- The inner most layer mounted to the BP by its extended supports.
- Layer 2-4 incorporate the intermediate support for installation. Layers 3 and layer4 share one common intermediate support.
- The intermediate supports are assembled by two parts to facilitate installation.

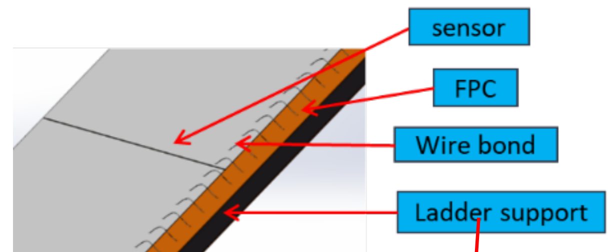




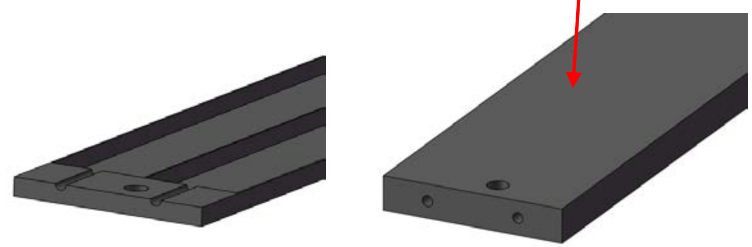
Ladder and support

- **Ladder components** (similar to previous VTXD prototype)

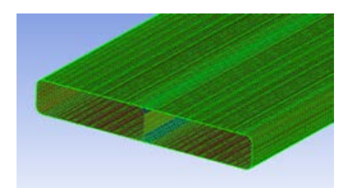




- **The ultra-light ladder support**

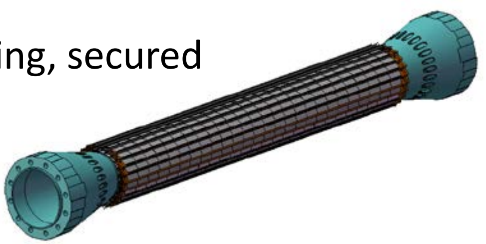


  - Size: 3.2 mm × 17.3 mm × 682mm
  - Material - high modulus CFRP
  - Feasible section design
  - Layup design of laminate
  - Laminate thickness of the shell is 0.15 mm (equal to 0.05 % X/X_0) and *can be further reduced to 0.14 mm.*

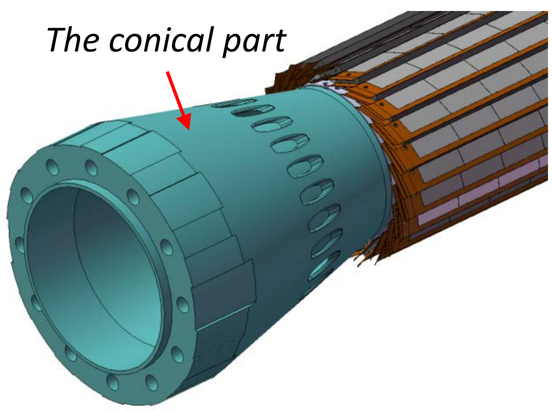


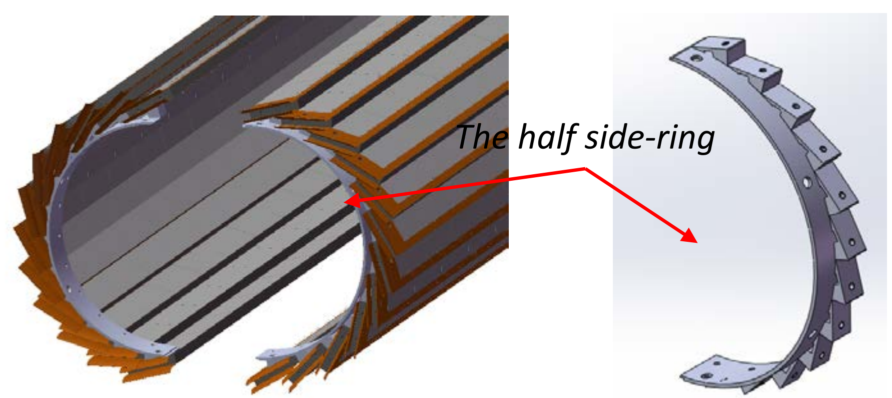
Ladder-based barrel

- The barrel provides **hermetic sensitive layers with minimal ladders**
  - The barrel consists of two half-barrels
  - Each half barrel assembled by two half side-rings at ends and ladders connected to these rings.
  - The ladders aligned with the serrated faces of the side- ring, secured with screws.



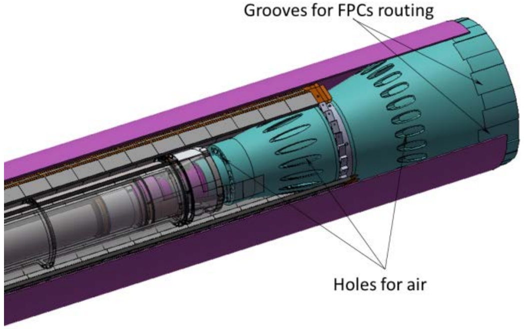
- **Barrel installation on the beam pipe (BP)**
  - Pre-assemble the half barrels, then install and secure them with screws on the intermediate conical parts (in green) of the BP assembly.

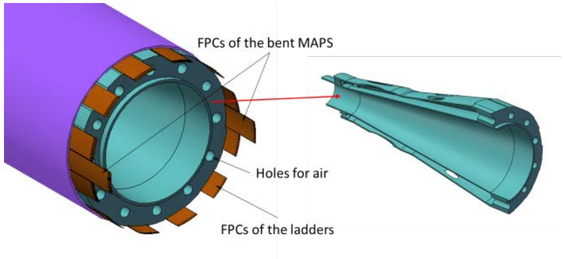




Cable routing and air ventilation

- **Only FPCs of the VTXD need to be routed out of the BP assembly** (outside the BP assembly then transfer to optical fibers via connectors)
  - ✓ For the cylinders: FPCs routed along their extended supports, converged at ends of layer4, then go through the conical part via grooves
  - ✓ For the ladders: converge FPCs of two adjacent ladders into one conduit guided by a frame, through the conical part via specified grooves
- **To improve air ventilation for the entire detector**
  - ✓ The conical part functions as the VTXD's air distributor, with hole groups facing different zones
  - ✓ Slotted holes on the local support and extended support of the cylinder assemblies
  - ✓ The slotted intermediate support, notably the frame-style one for layer3-4 reduce air blockage





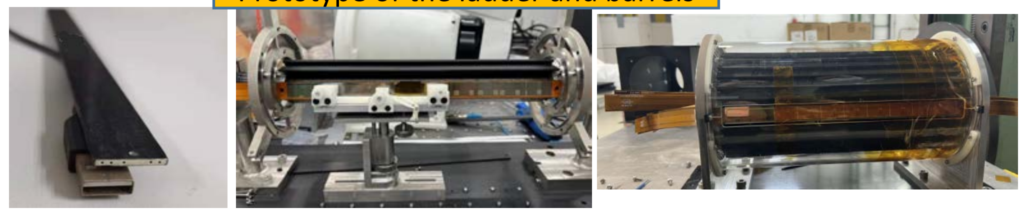
- **FPCs routing test on a half dummy VTXD model indicates no show-stopper**

Previous mechanics related R&D

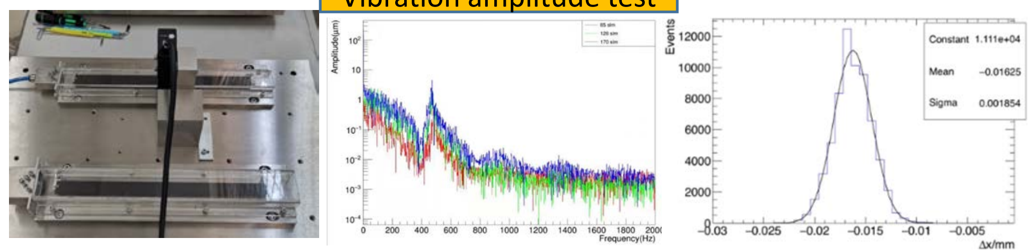
- **A flat MAPS based VTXD prototype** has been developed and evaluated (backup now)
  - Ladder(length=273 mm) /CFRP support
  - 3 layers of ladder-based barrels
  - Air cooled/fan
  - Ladder support test with static and dynamic loads (force air flow) on dedicated platforms

- **The overall structural performance verified by the prototype beam test** (vibration and isolation, temperature all meet requirements)

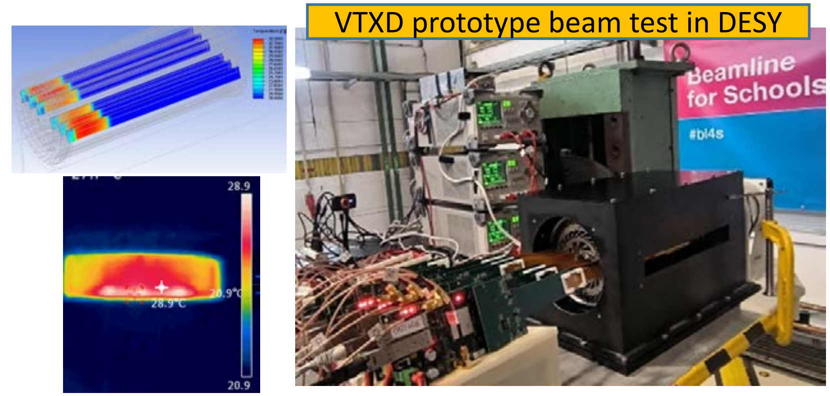
Prototype of the ladder and barrels



Vibration amplitude test



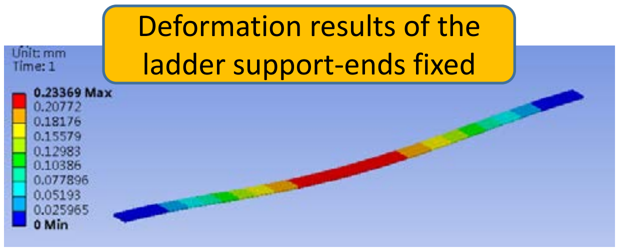
VTXD prototype beam test in DESY

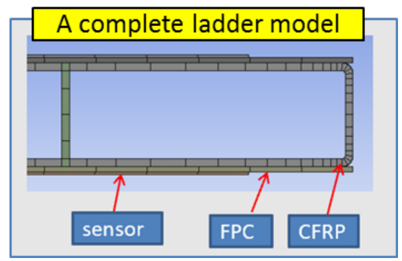


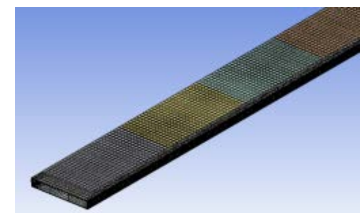
FEA of the ladder and bent MAPS

■ The ladder support

The simulation of the thin-walled structure with detailed CFRP layup design **resulted with acceptable deformation and very low IRF** (<0.02), under full load including weight of the sensors, FPCs and glue.







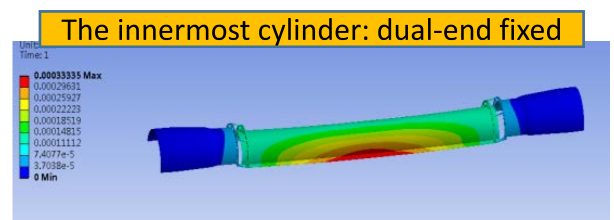
Previous FEA of the shorter ladder support VTX prototype showed that a complete ladder deforms 20% lower than the bare ladder support under full load.

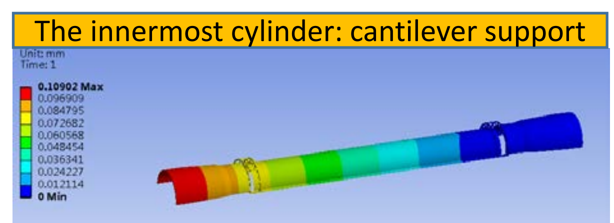
■ The bent MAPS cylinder assemblies.

Multiple configurations to assess structural deformation and chip stress distributions:

- Top-bottom assembly vs. left-right assembly
- Dual-end support vs. cantilever support

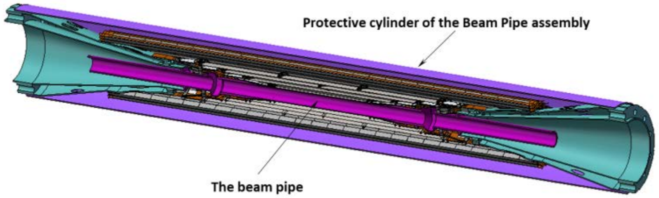
The results indicate that for each case the deformations is minimal and chip stresses at safe level.





VTXD Cooling

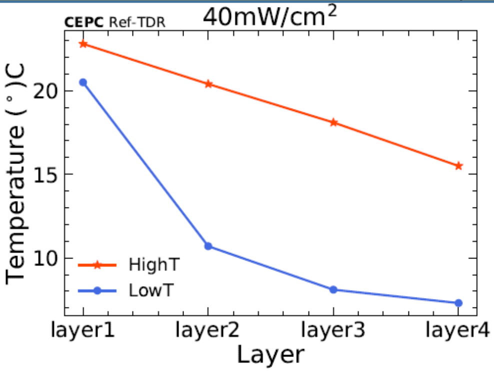
- **Cooling requirement**: detector operating temperature within 30 degrees Celsius
  - Detector power dissipation (same for ladders and bent MAPS) : 40 mW/cm^2
  - Total heat generation: 250 W (barrel /190 W , bent MAPS cylinders /60 W)
- **Forced air cooling** (driven by the detector power dissipation and very stringent low material requirement)
- **Cooling simulation conducted** (separately for barrel and cylinders)
  - Inlet air temperature 5 ℃
  - Beam pipe temperature considered



Simulation results of the barrel

Air flow(m/s)	Total heat generation of the barrel (W)	Max/min temperature on ladder (Celsius)
3.5	190	29.4/7.5

Simulation results of the bent MAPS cylinders



The simulation results indicate:

- ✓ airflow >= 3.5 m/s for effective cooling of the entire VTXD
  - higher temperature gradient on ladder/barrel
  - sufficiently low temperature with lower gradient on all cylinders, even the innermost layer (0.3mm from BP, no airflow)

VTXD Cooling

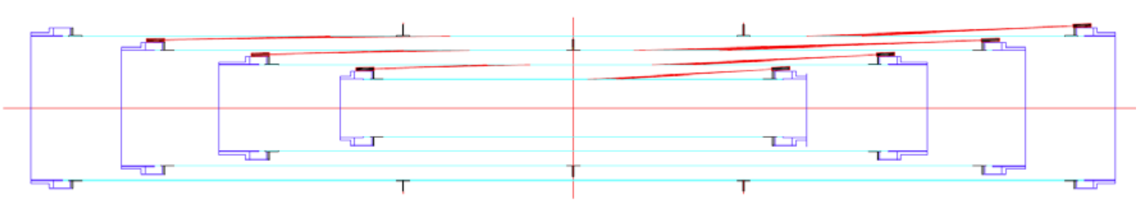
◆ **Vibration caused by air cooling**

- The plan for evaluating the vibration effect of the baseline design is to prototype and test the ladder and cylinders

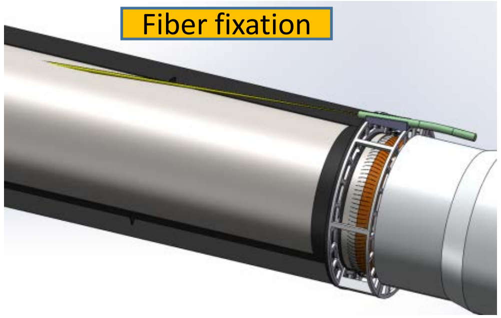
◆ **Real-time monitoring**

- A laser based alignment system is proposed to install for tracking movement of the MAPS sensors caused by environmental factors like vibration, temperature, humidity, etc.
- Laser induced to each layer of cylinder via fiber with its head fixed on the support of the cylinder, facing specified location

A laser-based online alignment monitoring system



Fiber fixation



Summary

- The overall support structure of the VTXD and its integration with the BP assembly has been designed.
- Structural and thermal simulations have been performed and related results posing no show-stopper
- More R&D studies to be conducted
  - simulations for realistic mode
  - a mock-up of MAPS cylinder for mechanical performance test
  - prototyping of the bent MAPS and ladders