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The design of CEPC beam pipe、SIT and the connection structure

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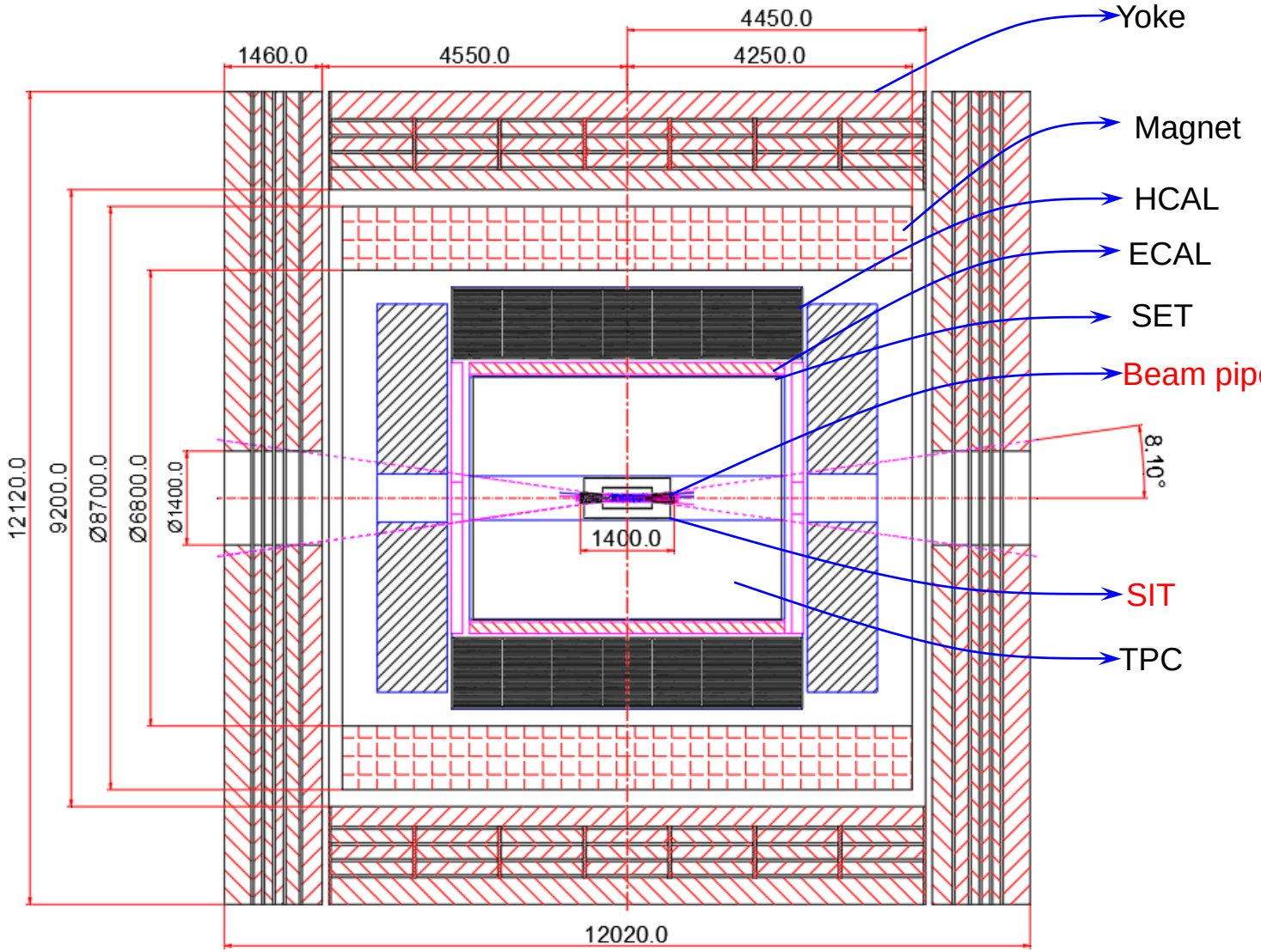
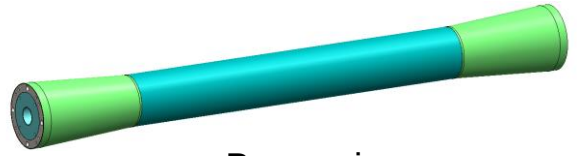
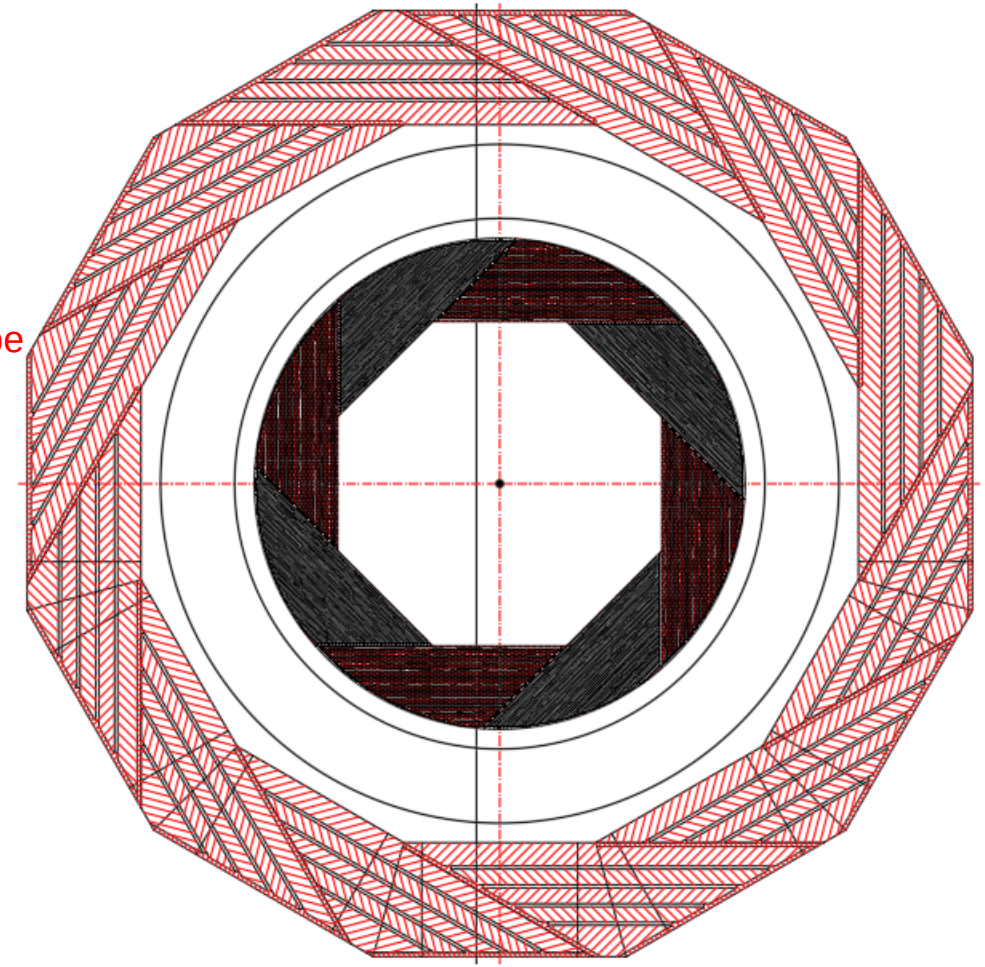
1. Introduction





Beam pipe



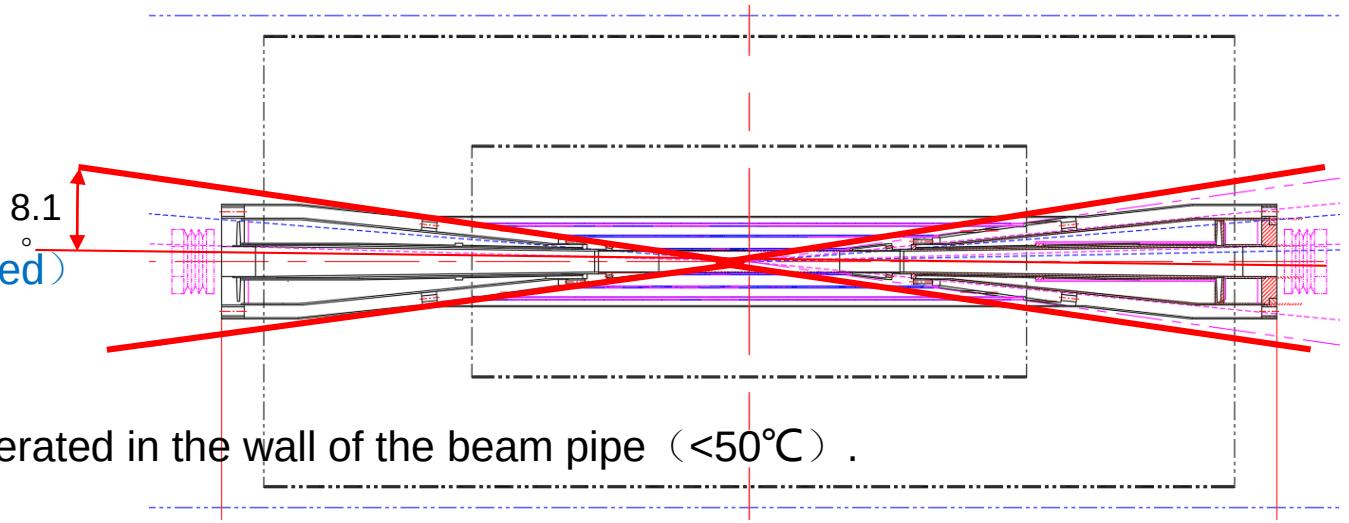
2. Design requirements

➢ Design boundaries and constraints:

1.Detection angle: 8.1° ---arccos(0.99)

2.Length: 1400mm（to be determined）

3.Inner diameter (Be): Ø28×0.5 mm（to be determined）



➢ Design requirements:

1. Designed cooling structure, take away the heat generated in the wall of the beam pipe（<50℃）.
2. Designed support structure for vertex and lumical.
3. Designed cooling structure, take away the heat generated by chip (<45℃).
4. The object mass in the detection angle area should be as little as possible.

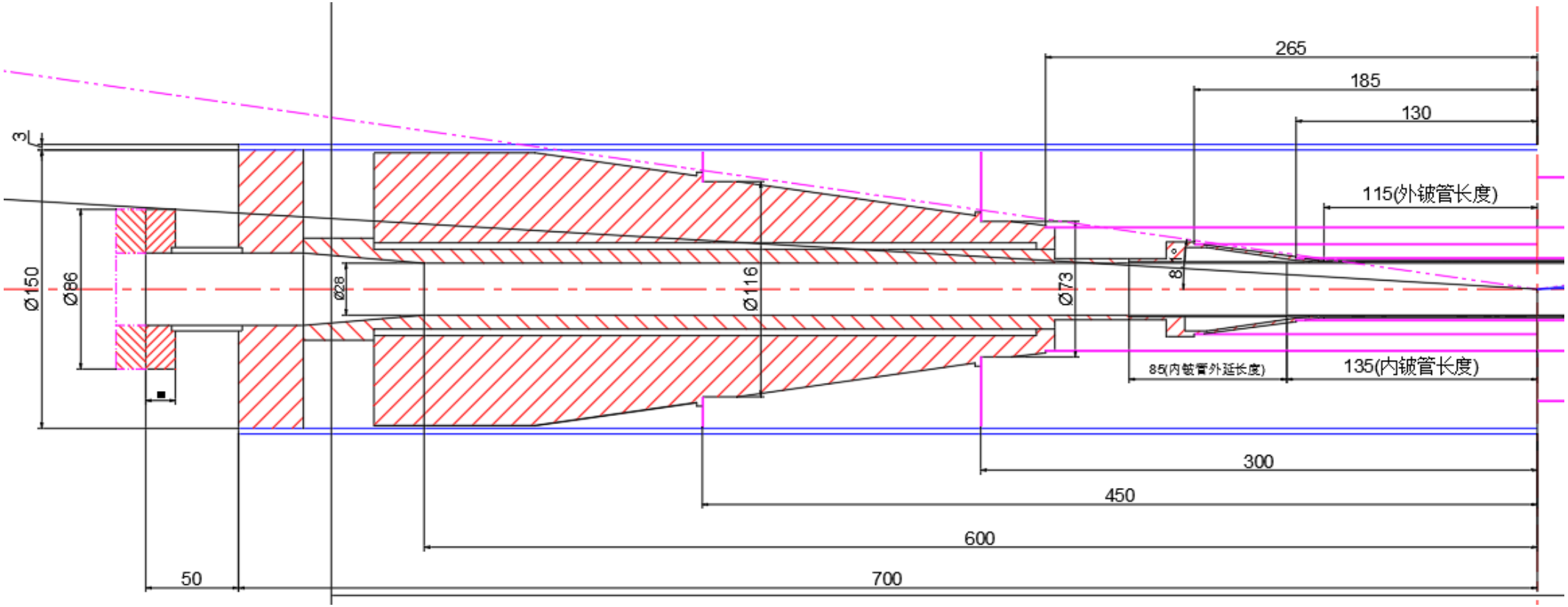
➢ Difficulty：

1. Due to the limitation of the detection angle, the space is tightly small, （Detector angle of BESIII: 21°）.
2. All water-cooled, air-cooled and oil-cooled cavities, cooling pipes and cables can only be distributed at both ends of the beam pipe, out of the detector angle.
3. The beam pipe structure should be designed according to the vertex and lumical, and The structure of vertex and lumical need to match the beam pipe；
4. Physics and mechanics require multiple version iterations to determine the appropriate structure.

3. Improved design of beam pipe （Ver.20190404）

- **preliminary design**

Design consideration： According to BESIII and foreign spectrometer, the central Be pipe is cooled by paraffin.

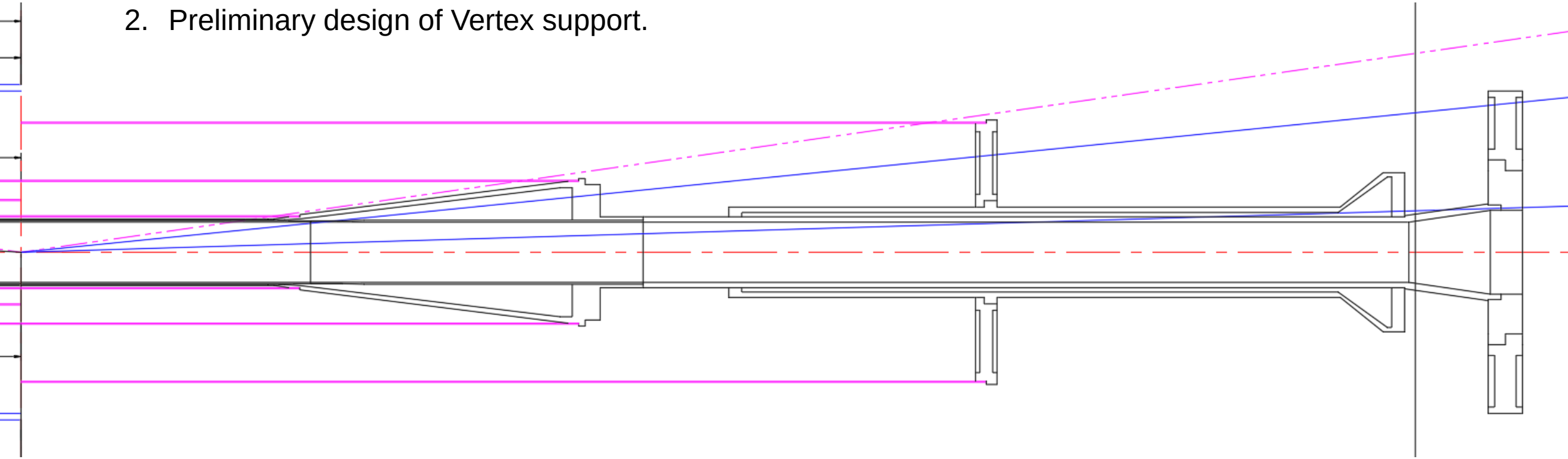


Existing problems: a lot of mass.

3. Improved design of beam pipe （Ver.20190721）

- Update：

1. thin structure with oil cooling and water cooling.
2. Preliminary design of Vertex support.

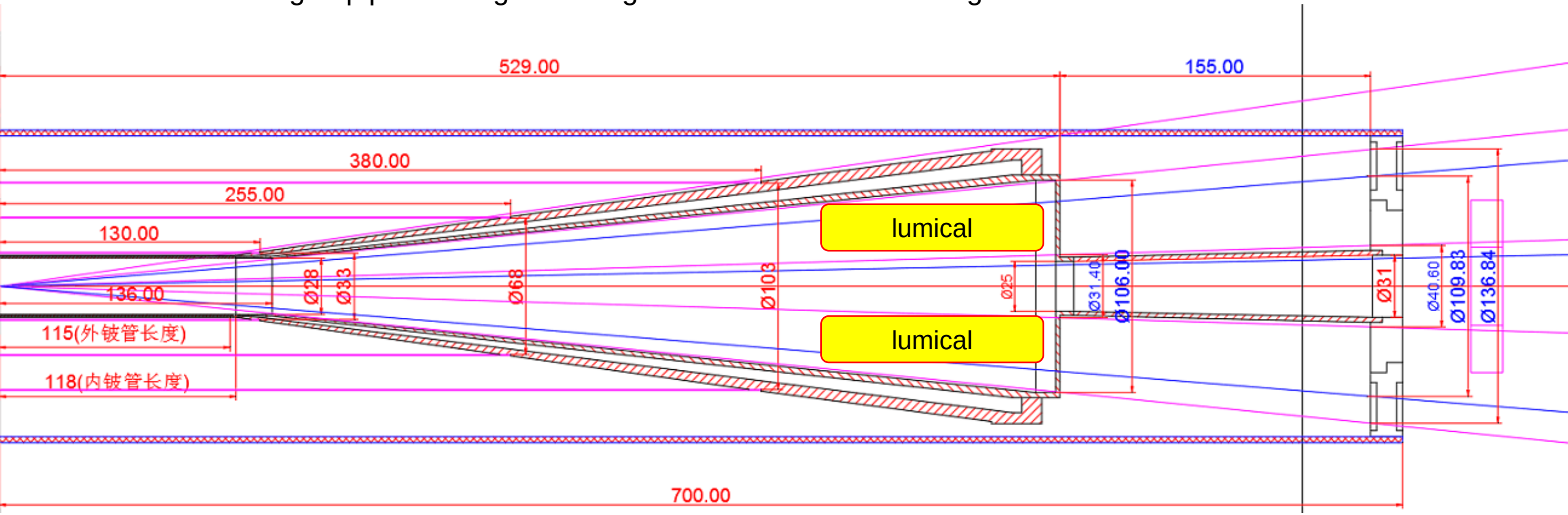


Existing problems: No cooling structure for vertex, and no installation location for lumical.

3. Improved design of beam pipe （Ver.20190817）

- Update：

1. Thin structure with all oil cooled.
2. The extending Al pipe is designed along the Lumical detection Angle in order to minimize the mass.

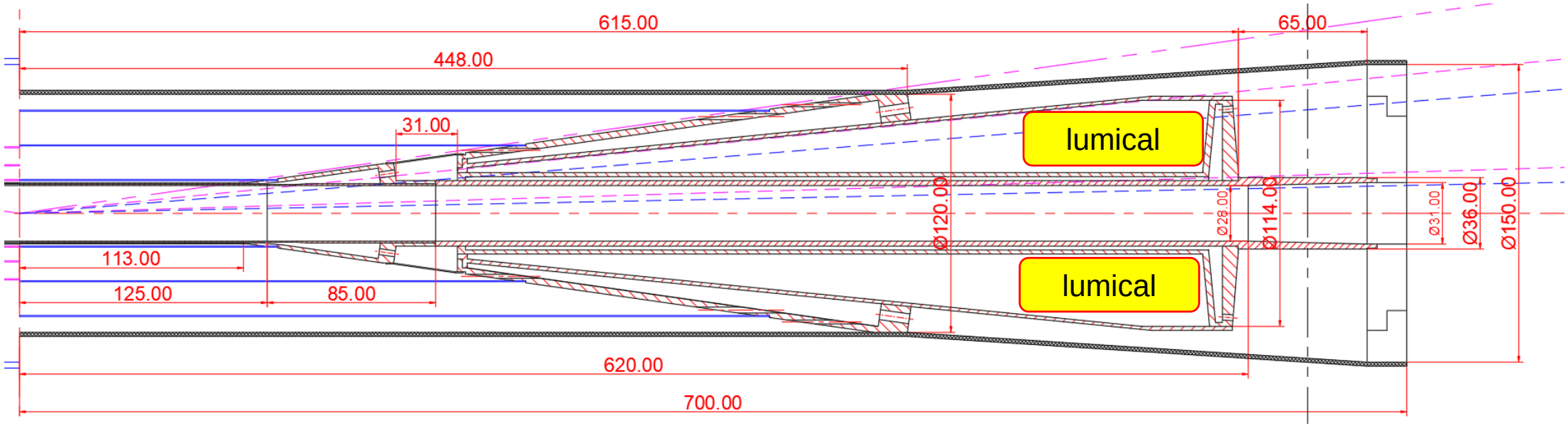


Existing problem：<u>High order mode heat cannot be removed by oil cooling.</u>

3. Improved design of beam pipe （Ver.20191113）

- Update：

1. Building block design.
2. Central Be pipe and Extending AL pipe are double-layer designed to cool the inner wall.
3. Supporting tube for vertex is designed with air window, which can distribute the air supply to the vertex of each layer.
4. Lumical installs outside the extending Al pipe.
5. The whole carbon fiber tube is used externally.

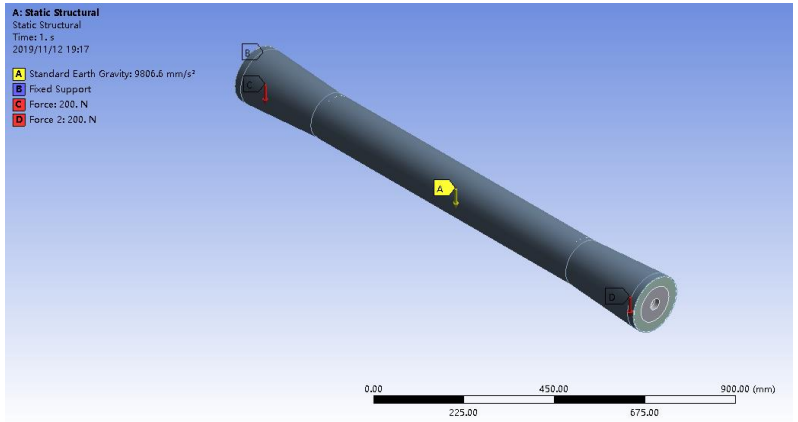


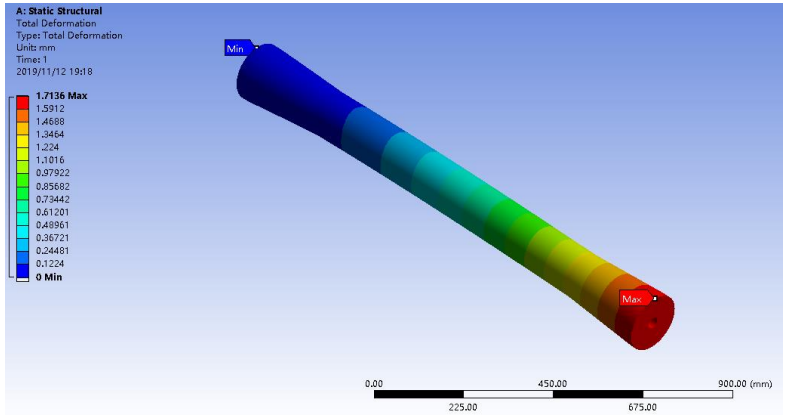
Summary :After communication with physics and detector for many times, this version of beam pipe is basically reasonable and feasible!

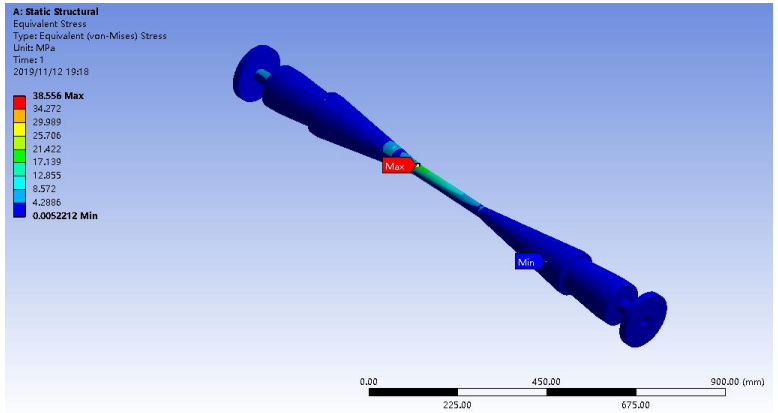
3. Improved design of beam pipe （Ver.20191113）

（1）Simulated cantilever installation， One end support, one end cantilever， lumical at each end, 20kg each， results： max deformation 1.7mm， max stress38.5MPa；

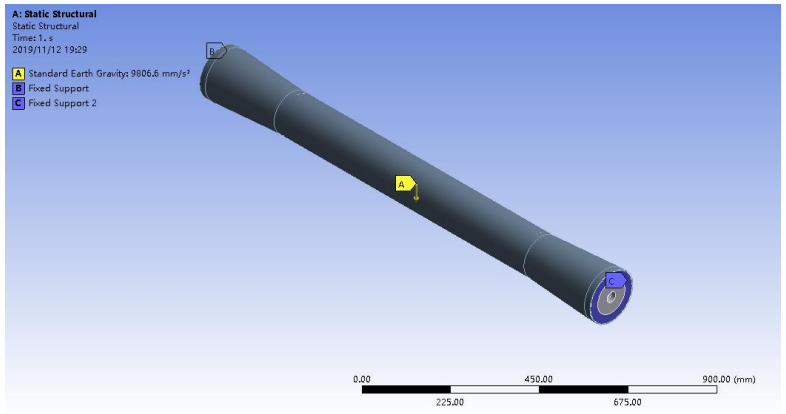
Lumical is unknown in this version, and the estimated weight is 20kg.

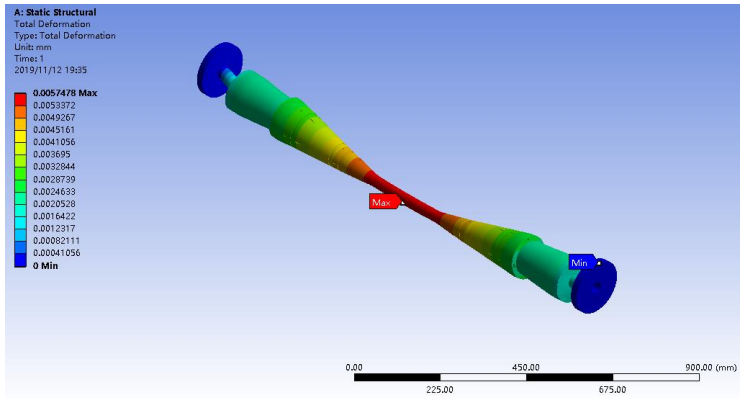


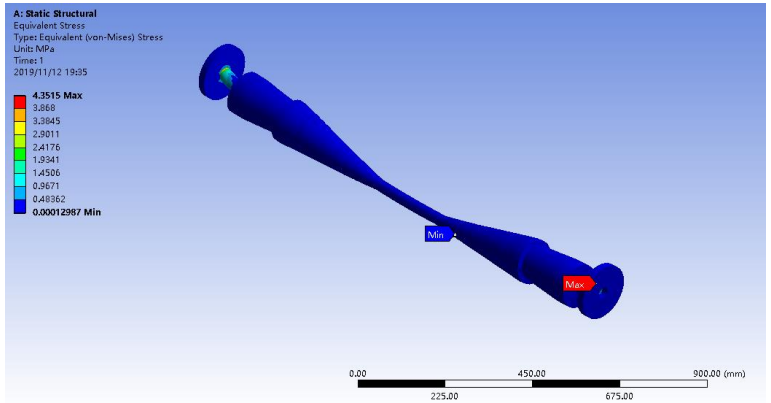




（2）Simulated installation in place， support on both ends， lumical on each end, 20kg each， results： max deformation 0.005mm， max stress 4.3MPa；

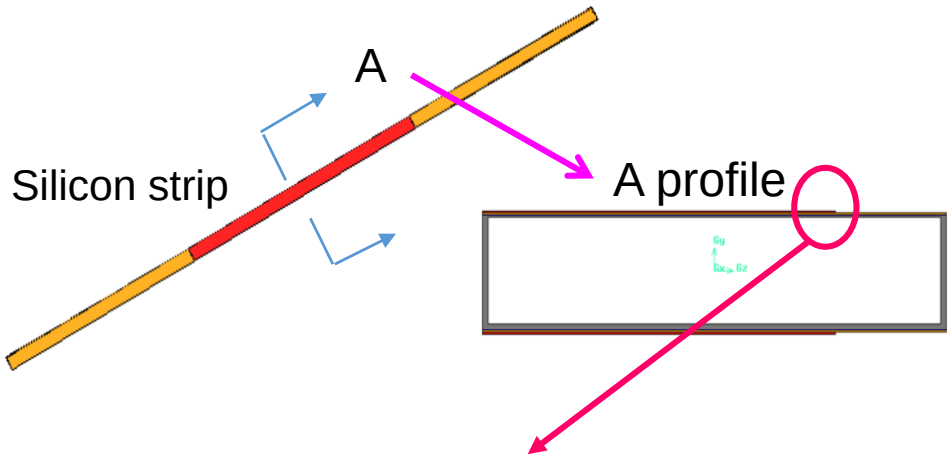






Conclusion: the structure with central Be pipe and outer whole carbon fiber tube is safe.

3. Improved design of beam pipe （Ver.20191113）



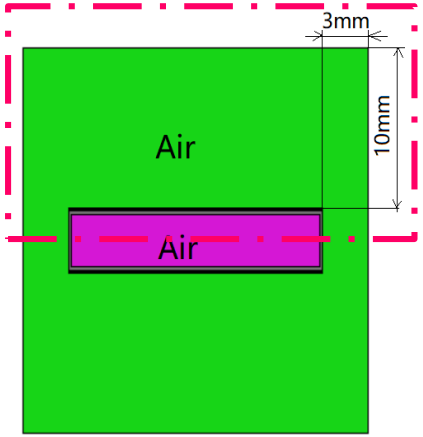
Exothermic layer(Si)：
25.7mm*12.8mm*0.05mm*10plates

Flexible circuit board(Kapton):
698mm*16.8mm*0.07mm

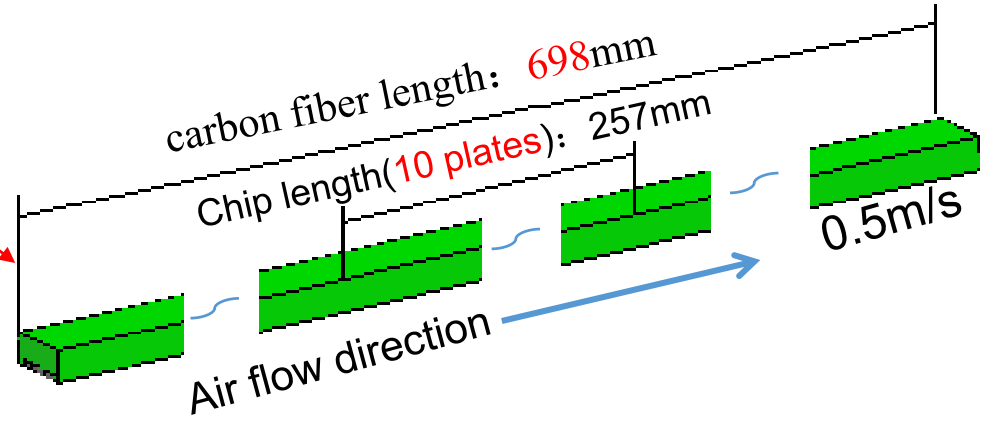
Carbon fiber：698mm*16.8*0.2mm

Material property

material	density	Specific heat	conductivity
	kg/m3	J/kg.k	W/K.m
Si	2419	713	149
kapton	1417	1260	0.2
carbon fiber	1810	710	0.52



Because of symmetry, using half to simulate



Calculation model with air

Results

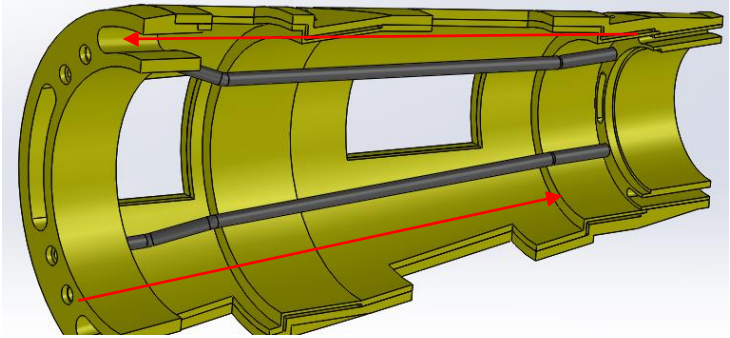
Heat flux	Maximum temperature	
mW/cm^2	0.3m/s	0.5m/s
	℃	℃
200	537.9	489.5
100	276.7	251.8
50	146.6	134.5

Existing problem：Only air cooling can't take away the heat generated by 10 chips.

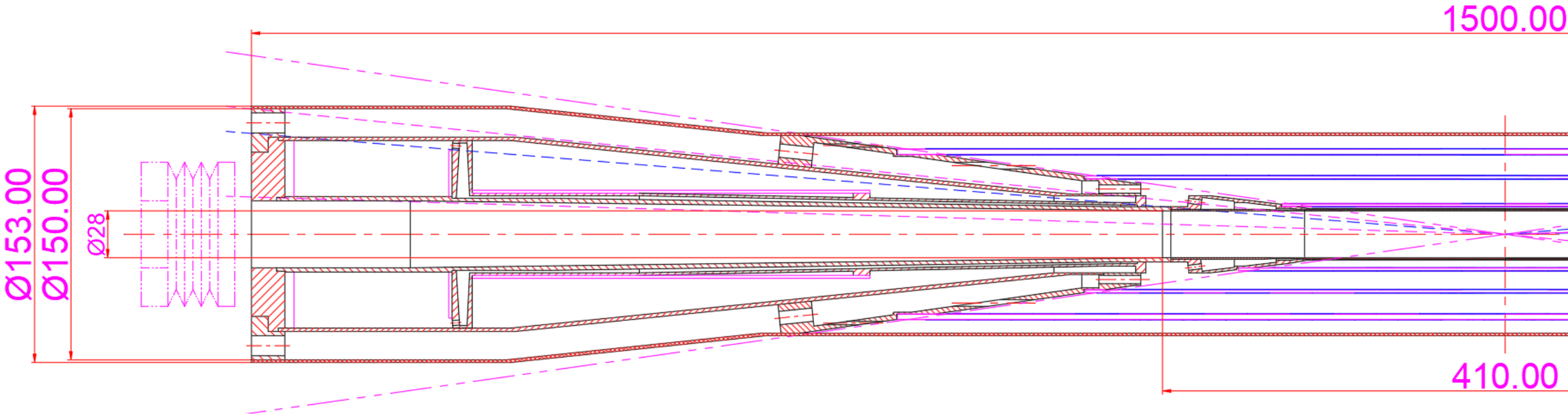
3. Improved design of beam pipe（Ver.20200624）

- Update：

1. a water-cooled sandwich structure is added to the support tube for vertex.
2. The length of beam pipe is changed from 1400 to 1500mm.



water-cooled sandwich structure

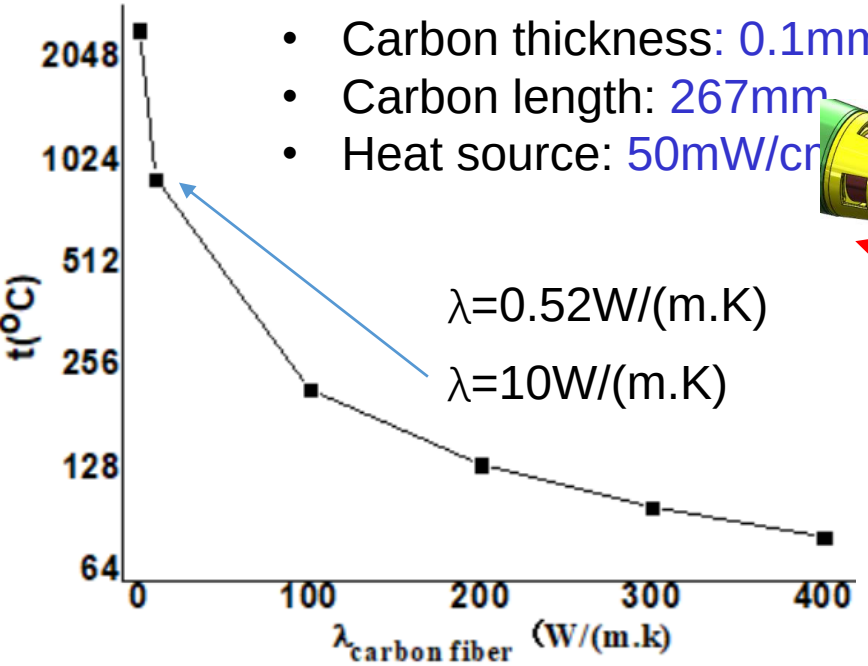


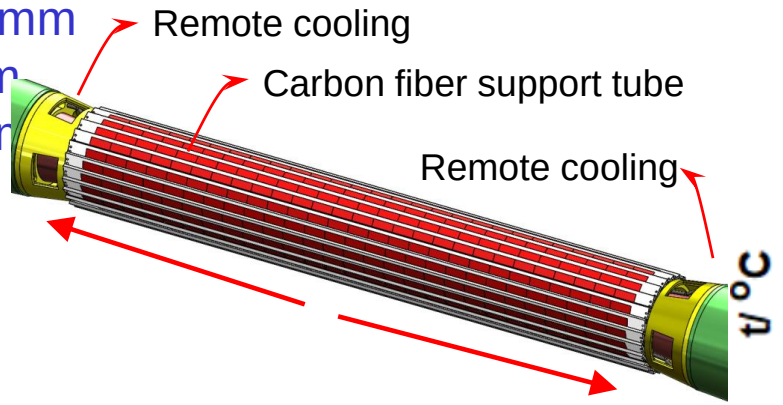
Summary: Remote cooling structure increases the vertex cooling effect!!

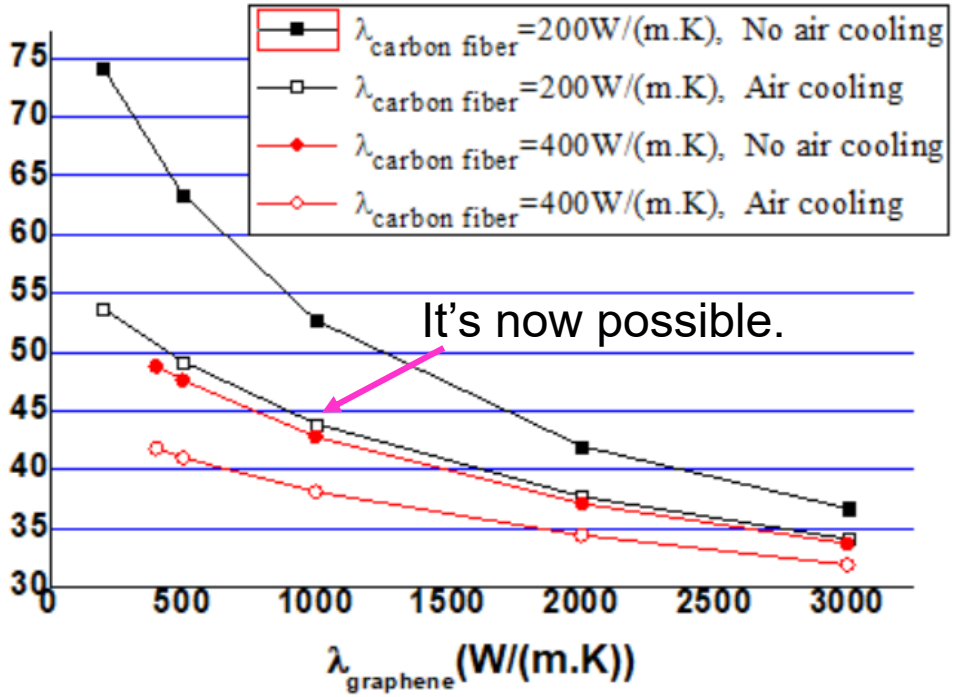
3. Improved design of beam pipe（Ver.20200624）

Calculation condition:

- Carbon thickness: 0.1mm
- Carbon length: 267mm
- Heat source: 50mW/cm



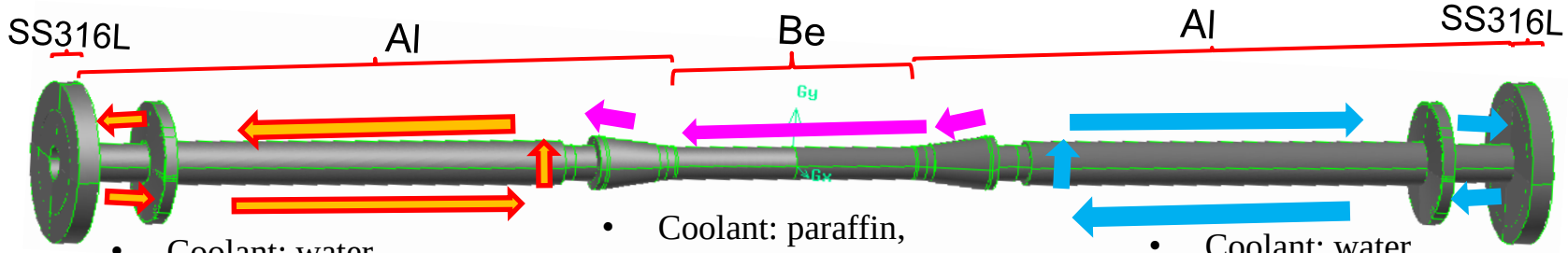




Existing problem： Because both the thermal conductivity section of carbon fiber support tube and the thermal conductivity coefficient of conventional carbon fiber are too small, which result in poor remote cooling effect.

Next step solution: high thermal conductivity carbon fiber (thermal conductivity >200W/(m.k)) + high thermal conductivity coating (thermal conductivity >1000W/(m.k)).

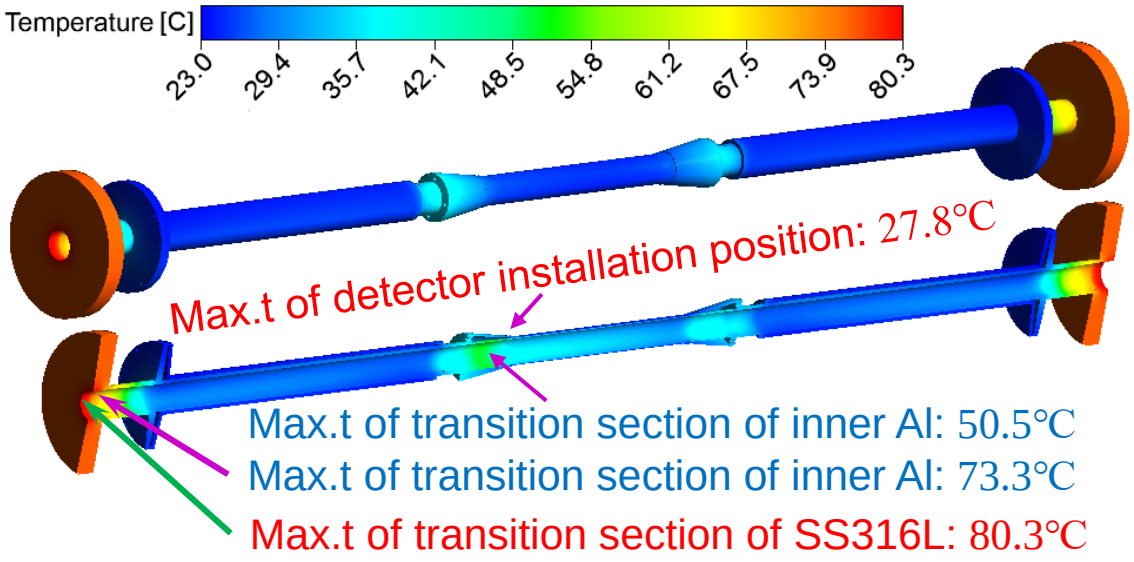
3. Improved design of beam pipe（Ver.20200624）



- Coolant: water,
- Two inlet, two outlet
- Inlet temperature: 23℃
- Inlet velocity: 3.4L/min

- Coolant: paraffin,
- Four inlet, four outlet
- Inlet temperature: 23℃
- Inlet velocity: 2.2L/min

- Coolant: water,
- Two inlet, two outlet
- Inlet temperature: 23℃
- Inlet velocity: 3.4L/min

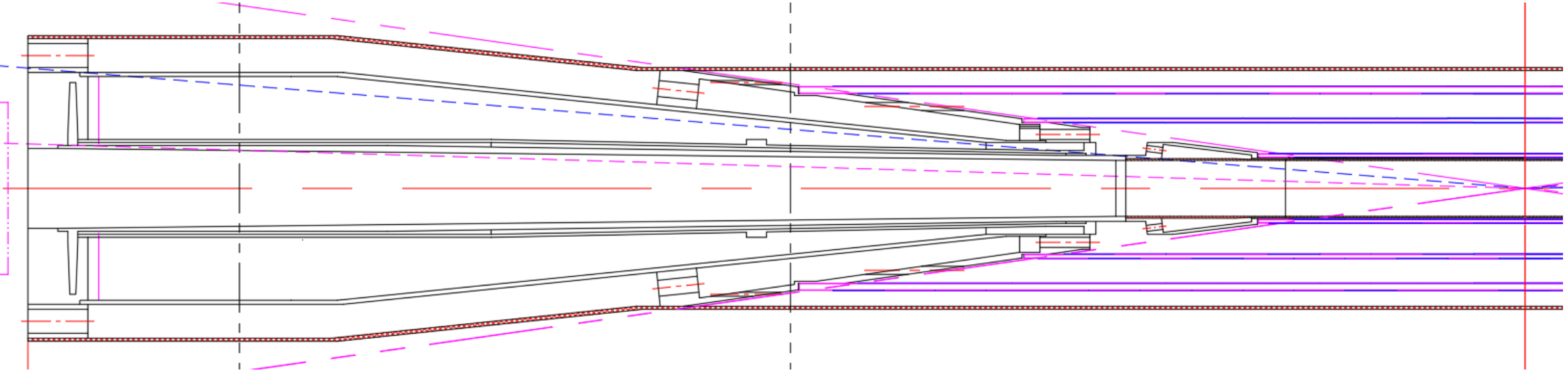


Existing problems: the temperature on transition section of extending Al pipe is too high (maximum 80.3℃)

3. Improved design of beam pipe （Ver.20200710）

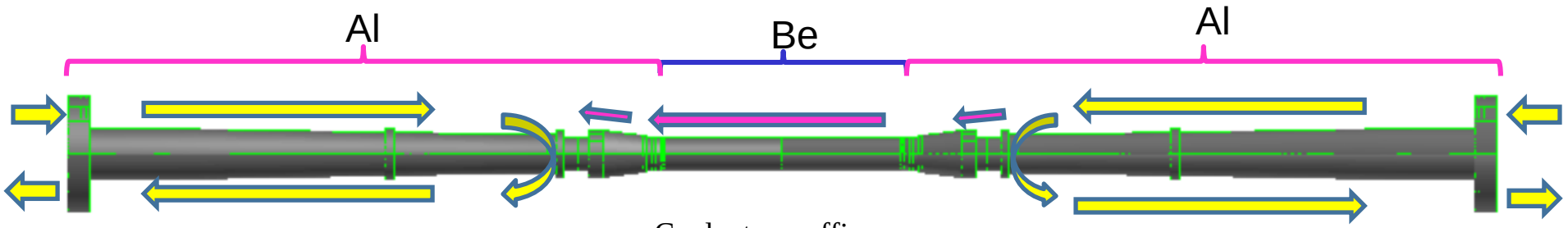
- Update：

1. Extend the extending AL pipe, and cancel the transition.
2. The External strengthen pipe is changed into a center carbon fiber cylinder with two tapered aluminum cylinder.
3. The length of beam pipe is changed from 1500 to 1400mm.



Summary :After several versions of iteration, the latest version can basically meet the detector support and primary cooling requirements!

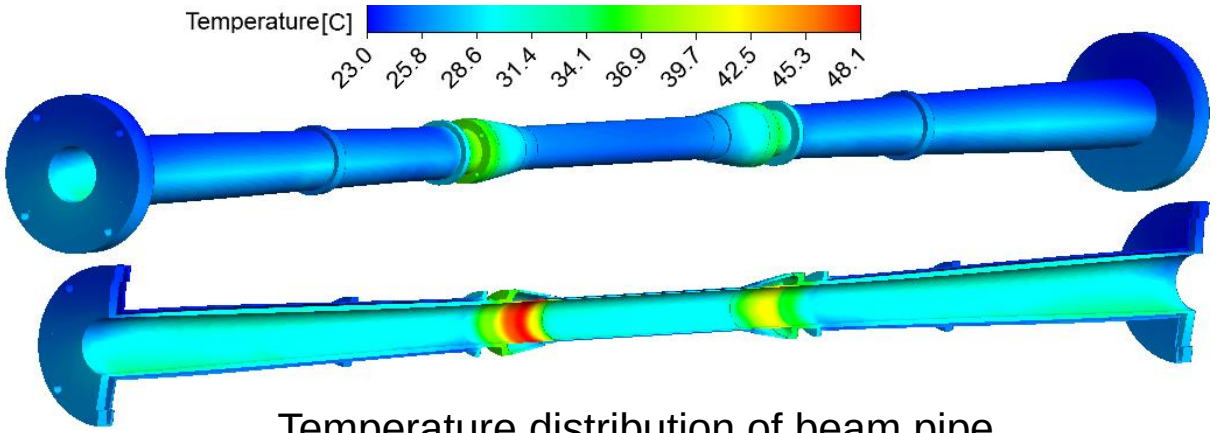
3. Improved design of beam pipe （ Ver.20200710 ）



- Coolant: water,
- Two inlet, two outlet
- Inlet temperature: 23℃
- Inlet velocity: 3.4L/min

- Coolant: paraffin,
- Four inlet, four outlet
- Inlet temperature: 23℃
- Inlet velocity: 2.2L/min

- Coolant: water,
- Two inlet, two outlet
- Inlet temperature: 23℃
- Inlet velocity: 3.4L/min



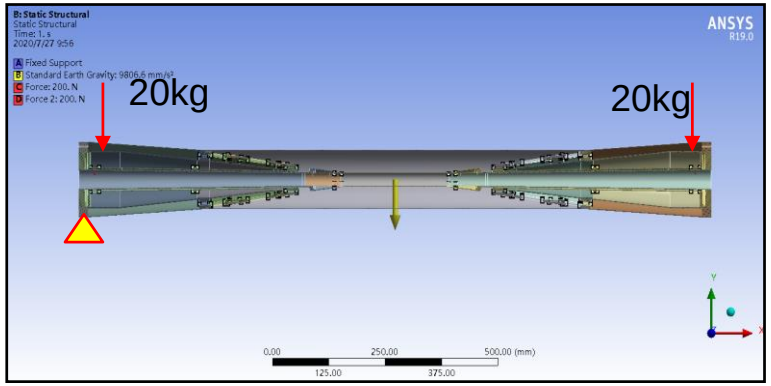
Temperature distribution of beam pipe

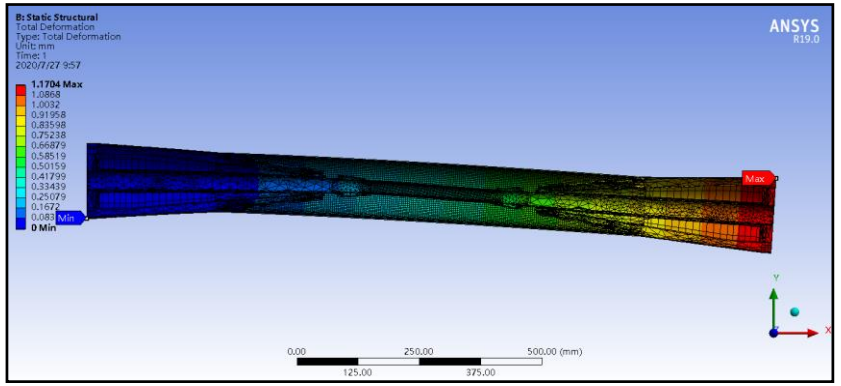
Summary :The inner wall temperature distribution of the beam pipe is lower than 50℃.

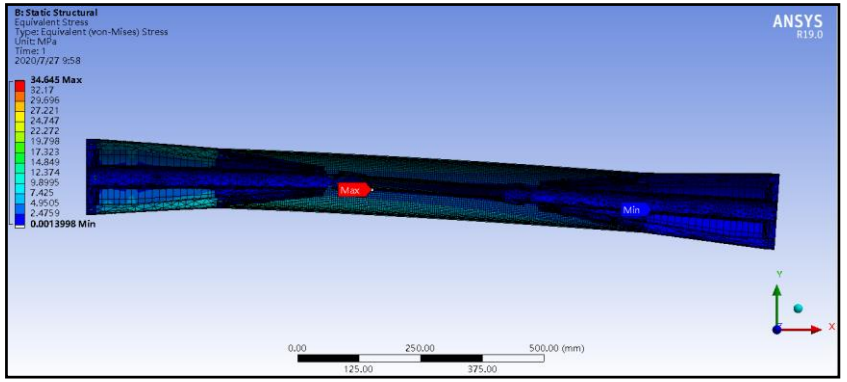
3. Improved design of beam pipe （ Ver.20200710 ）

(1) Cantilever installation， One end support, one end cantilever， lumical at each end, 20kg each， results： max deformation 1.2mm， max stress34.6MPa；

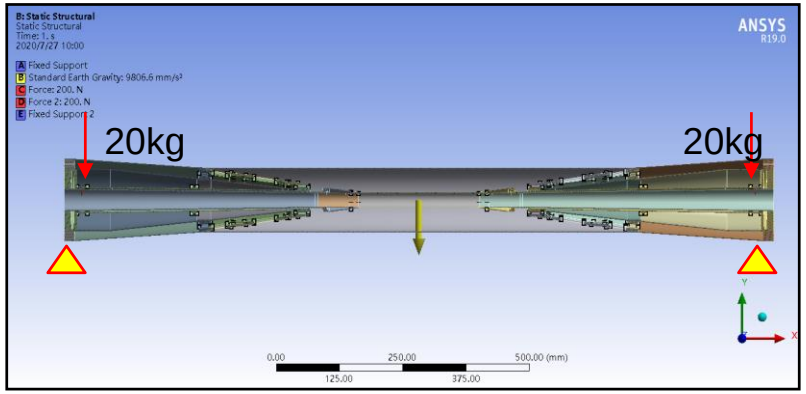
In this version, lumical is a thin carbon fiber structure. In order to compare with the previous analysis, 20kg load is still added at the end

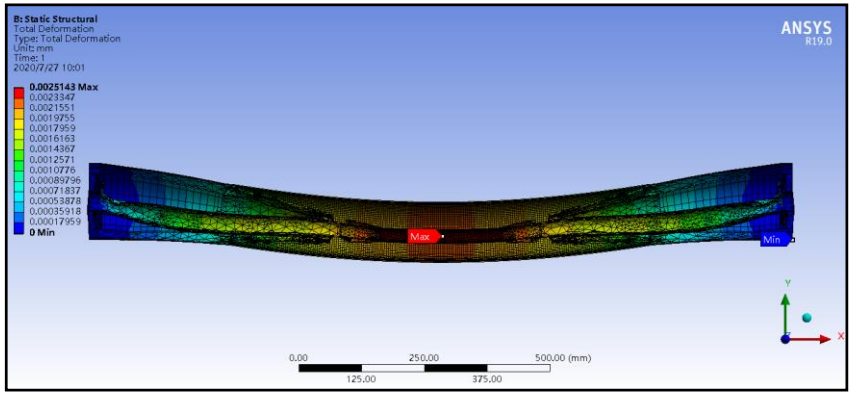


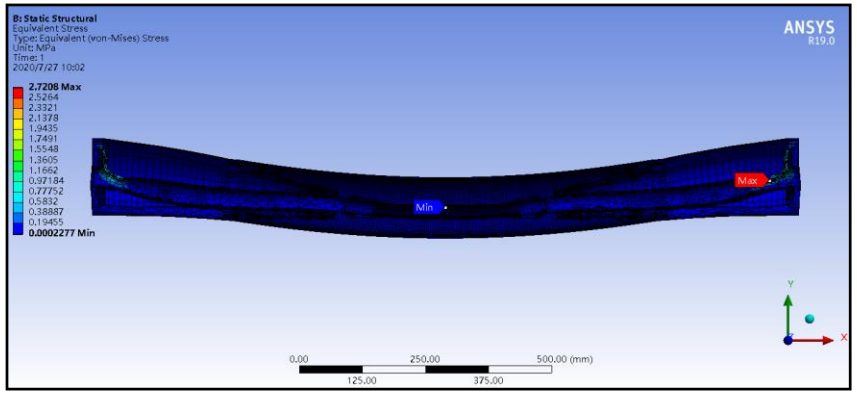




(2) Installation in place， support on both ends， lumical on each end, 20kg each， results： max deformation 0.0025mm， max stress 2.7MPa；



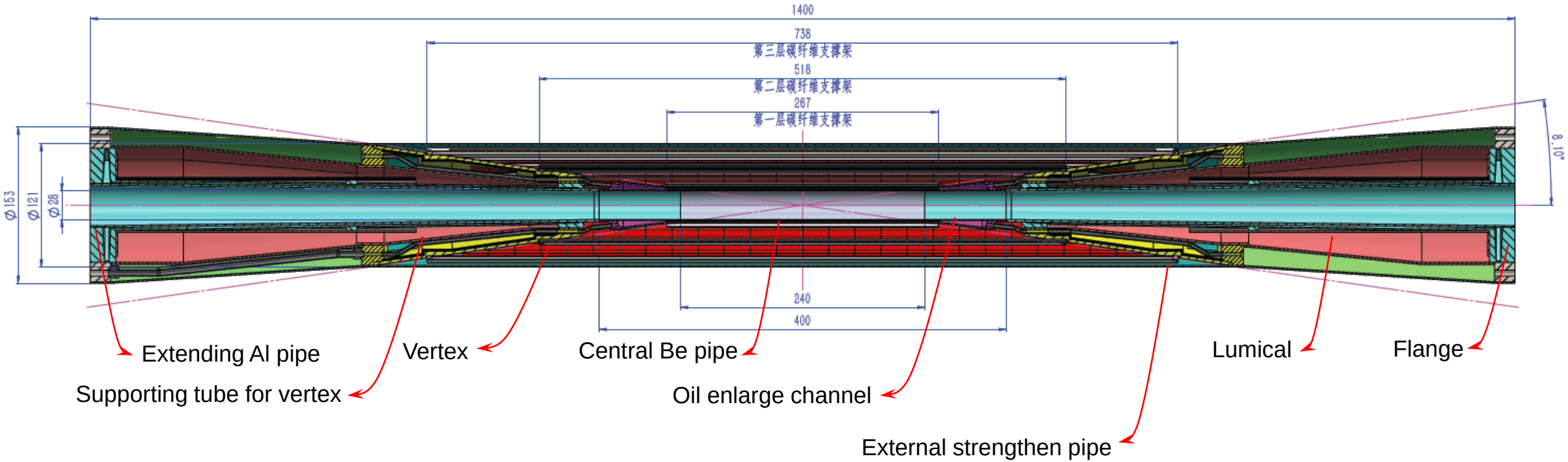




Conclusion: the structure with central Be pipe and a center carbon fiber pipe with two tapered AL pipe is safe.

4. Structure of Beam pipe （Ver.20200710）

4.1 Overall layout

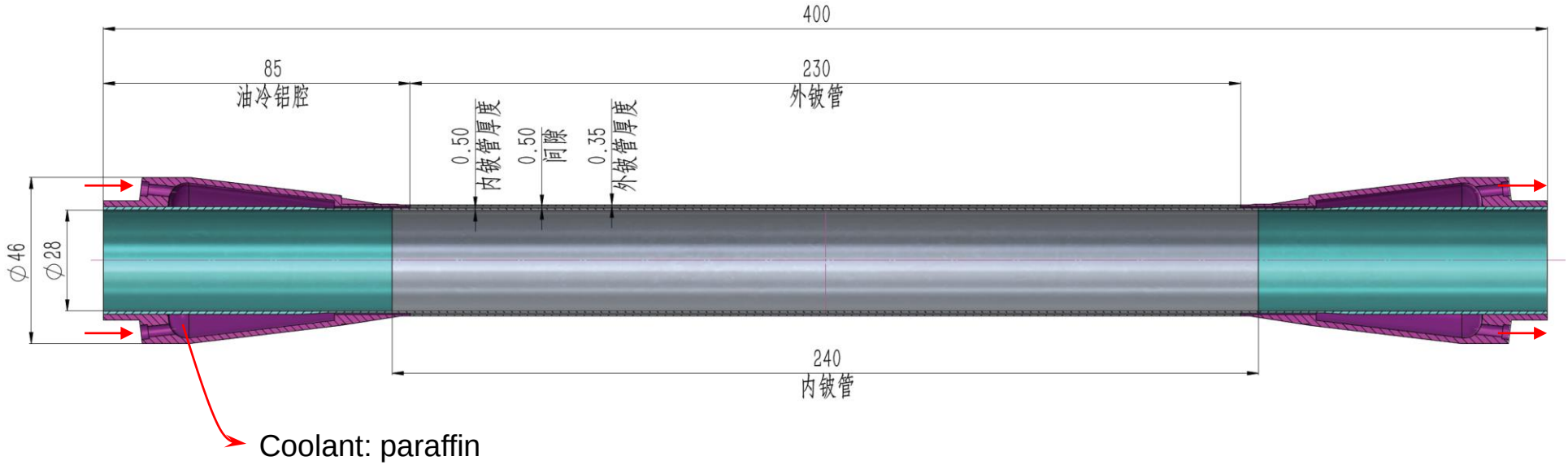


Summary：Building block design！

4. Structure of Beam pipe （Ver.20200710）

4.2 Central Be pipe

- Inner diameter (Be): Ø28×0.5 mm，length:240mm（BESIII： Ø63×0.8 mm，length:278mm ）
- Out diameter (Be): Ø30×0.35 mm，length:230mm（BESIII： Ø66×0.6 mm，length:220mm ）
- 0. 5mm Be can bear 3.3MPa，0.35mm Be can bear 0.93MPa，The structure meets the strength requirement.

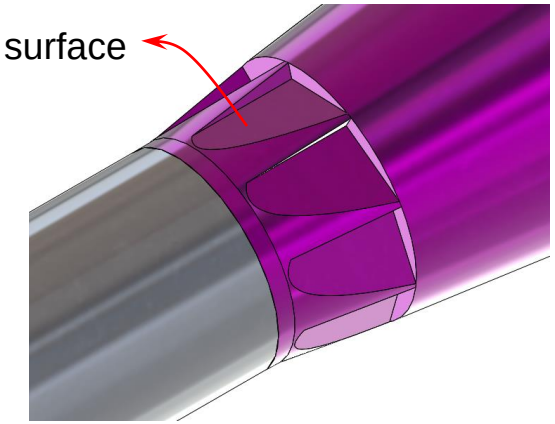


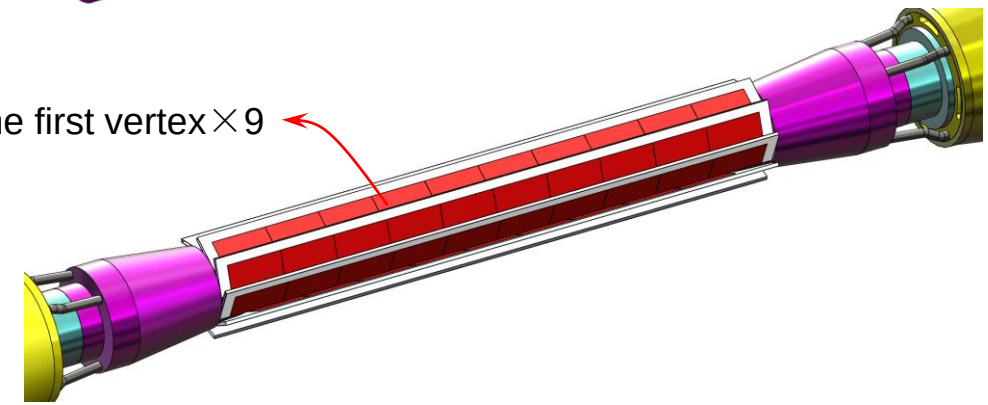
Difficulty: high vacuum requires the inner wall polishing, Be is brittle and hard, the processing of slender Be pipe is extremely difficult!

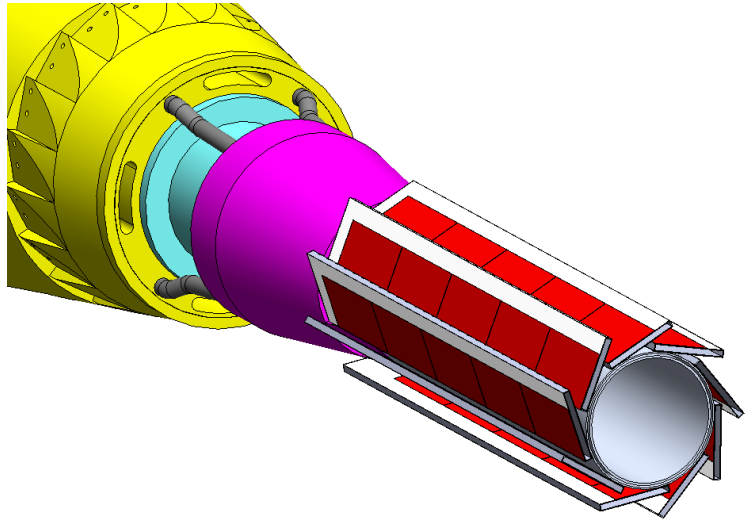
4. Structure of Beam pipe （Ver.20200710）

4.2 Central Be pipe

- The first layer vertex is mounted close to the center Be pipe.





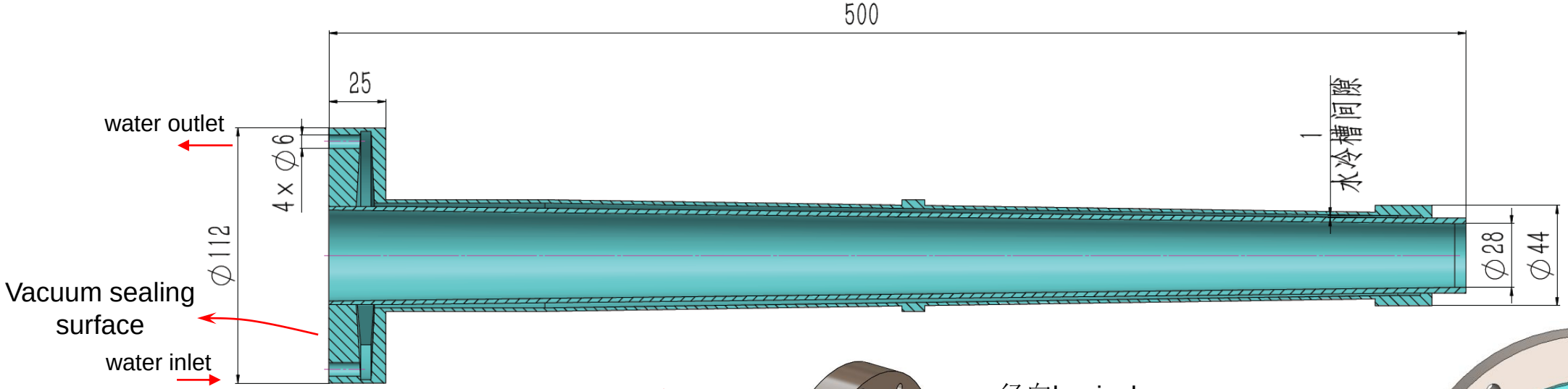


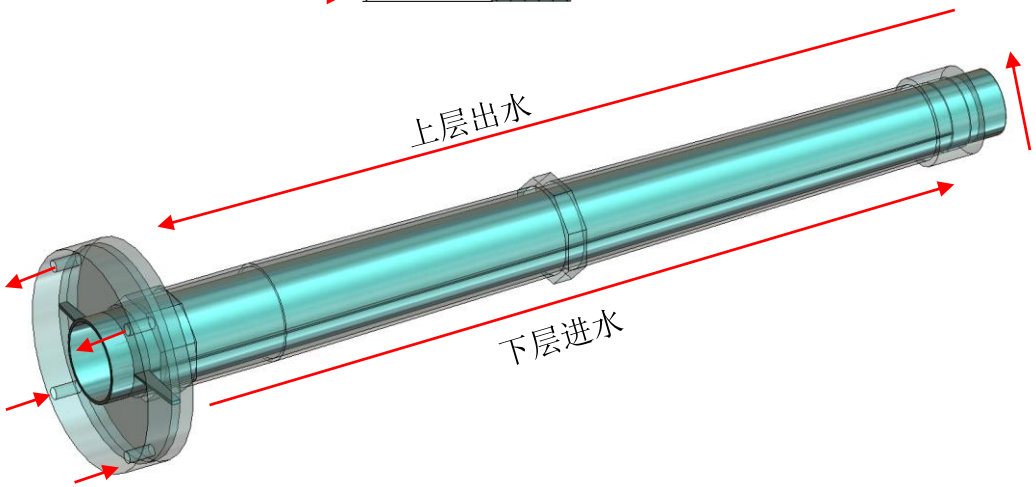
Summary：The heat of the first layer of vertex is removed by remote cooling through the oil cooled amplification chamber at both ends!

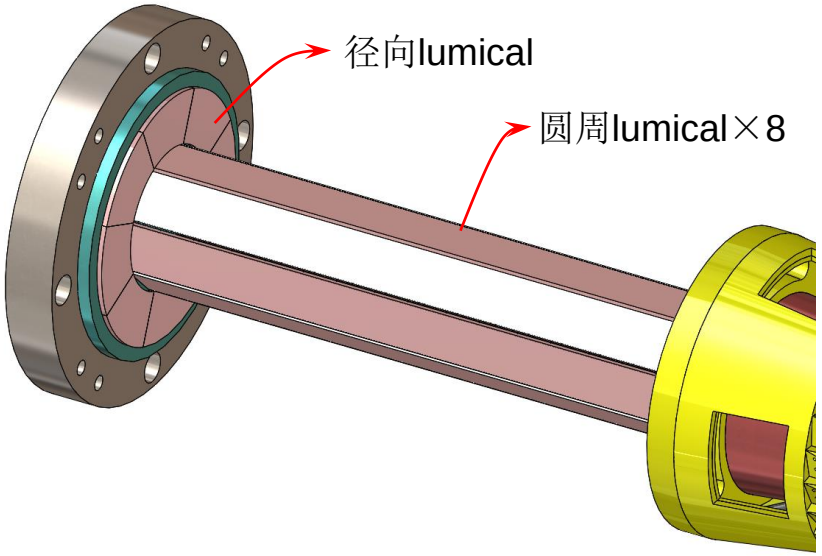
4. Structure of Beam pipe （Ver.20200710）

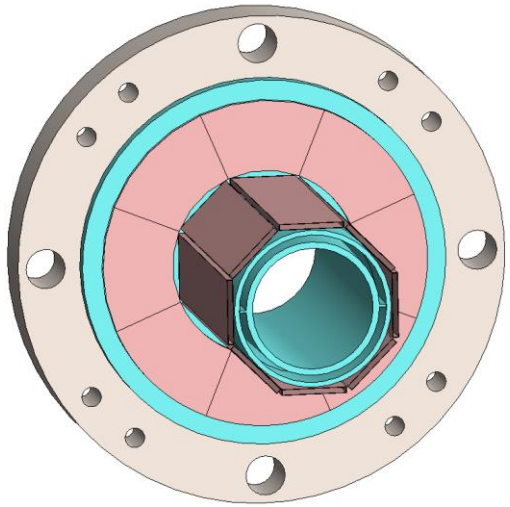
4.3 Extending AL pipe

- A water-cooled interlayer is located inside the extending AL pipe.
- The end face is butted with the accelerator vacuum tube.







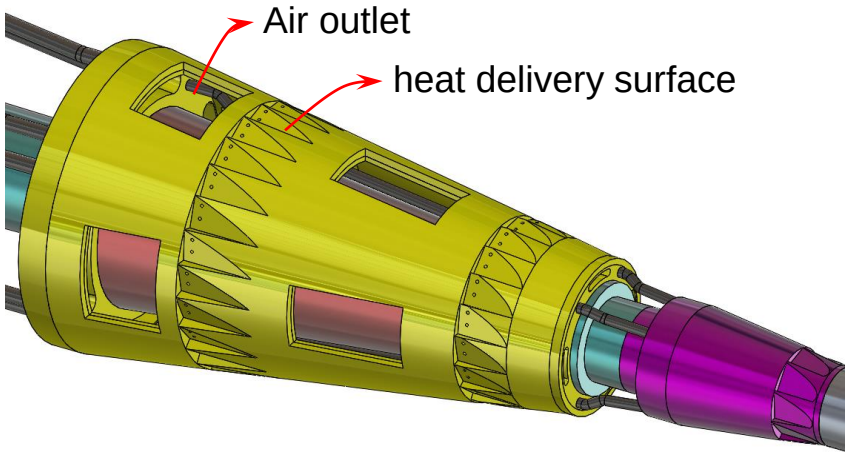


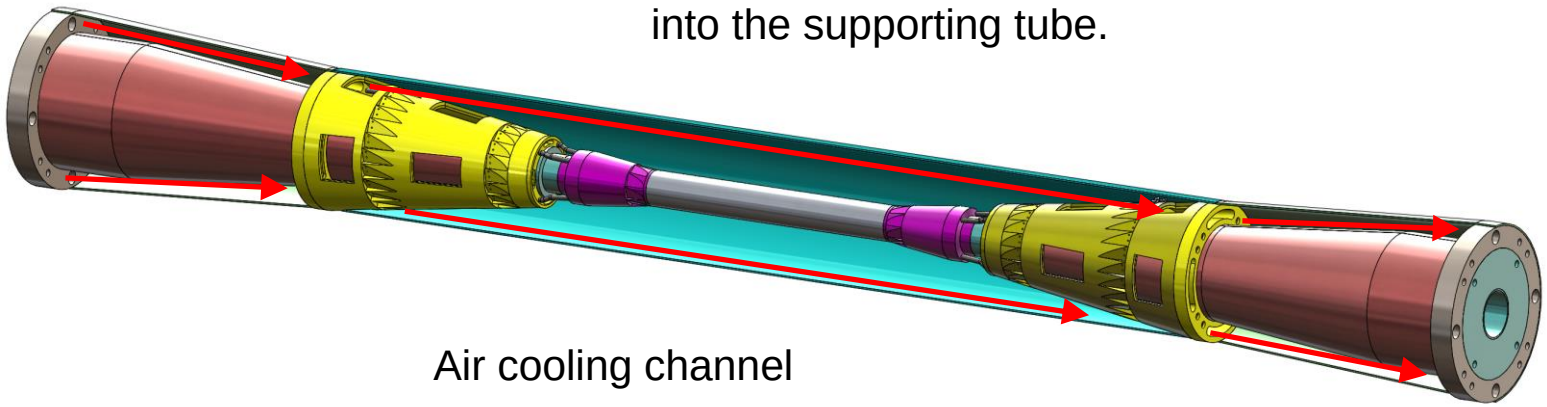
Summary： the high order mode heat and the lumical heat are taken away by water cooling.

4. Structure of Beam pipe （Ver.20200710）

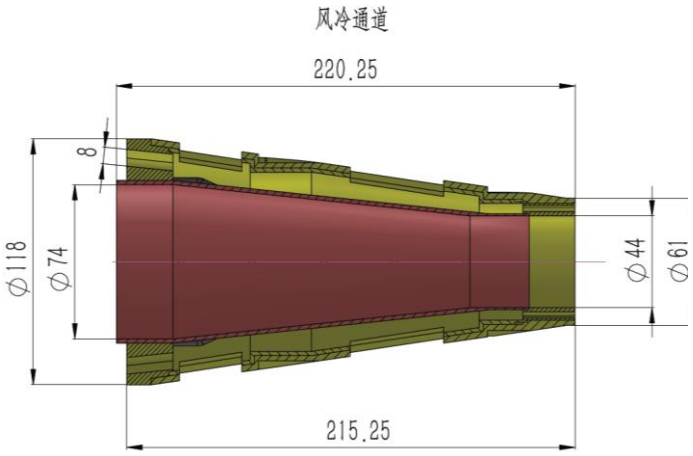
4.4 Supporting tube for vertex

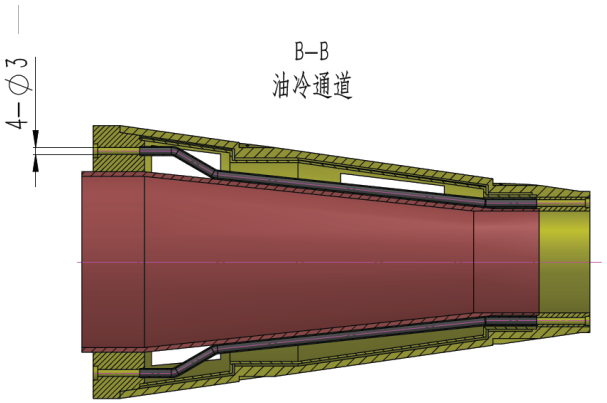
- Form air cooling passage from left to right;
- 1mm thick water-cooled interlayer is introduced into the supporting tube.

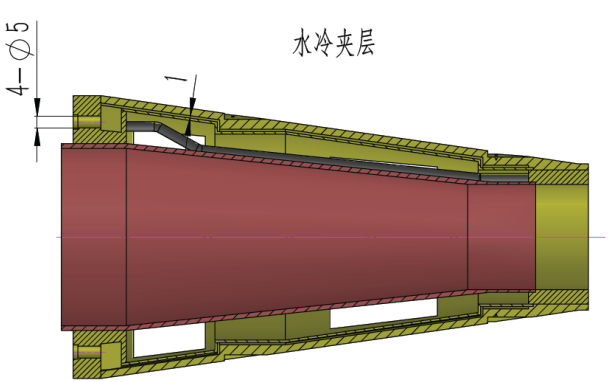


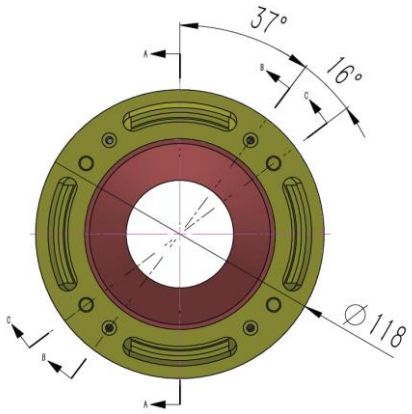


Air cooling channel





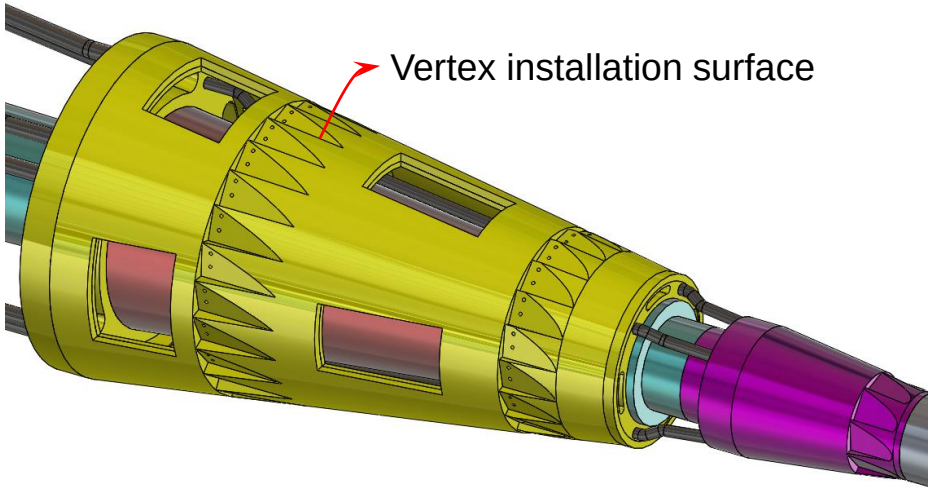


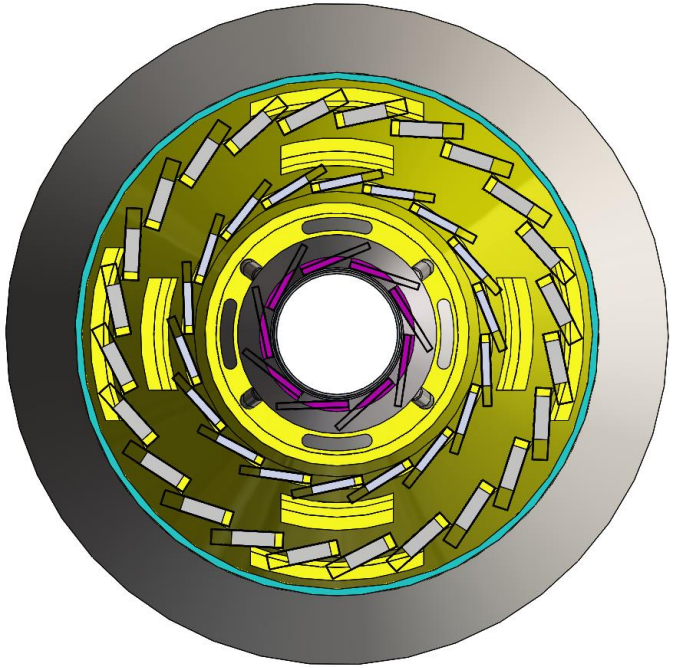


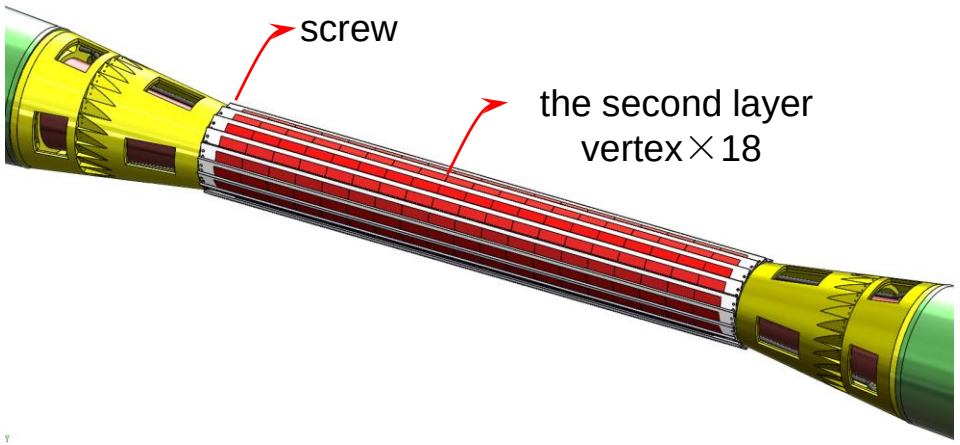
Difficulty: Air cooling channel + water cooling interlayer + embedded oil cooling pipe, very complex structure!

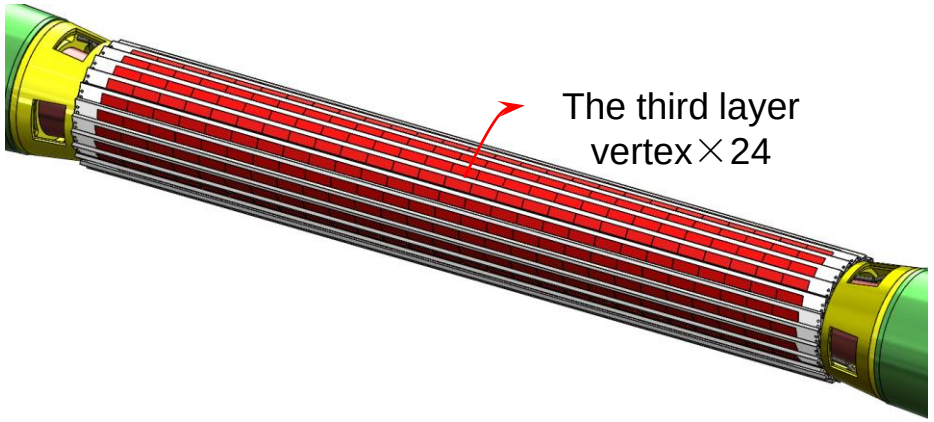
4. Structure of Beam pipe （Ver.20200710）

4.5 Supporting tube for vertex







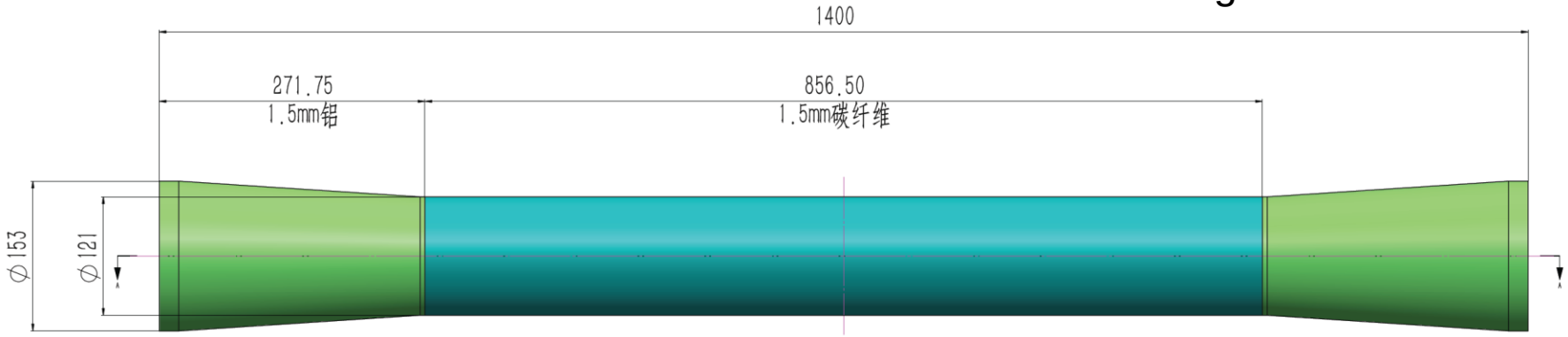


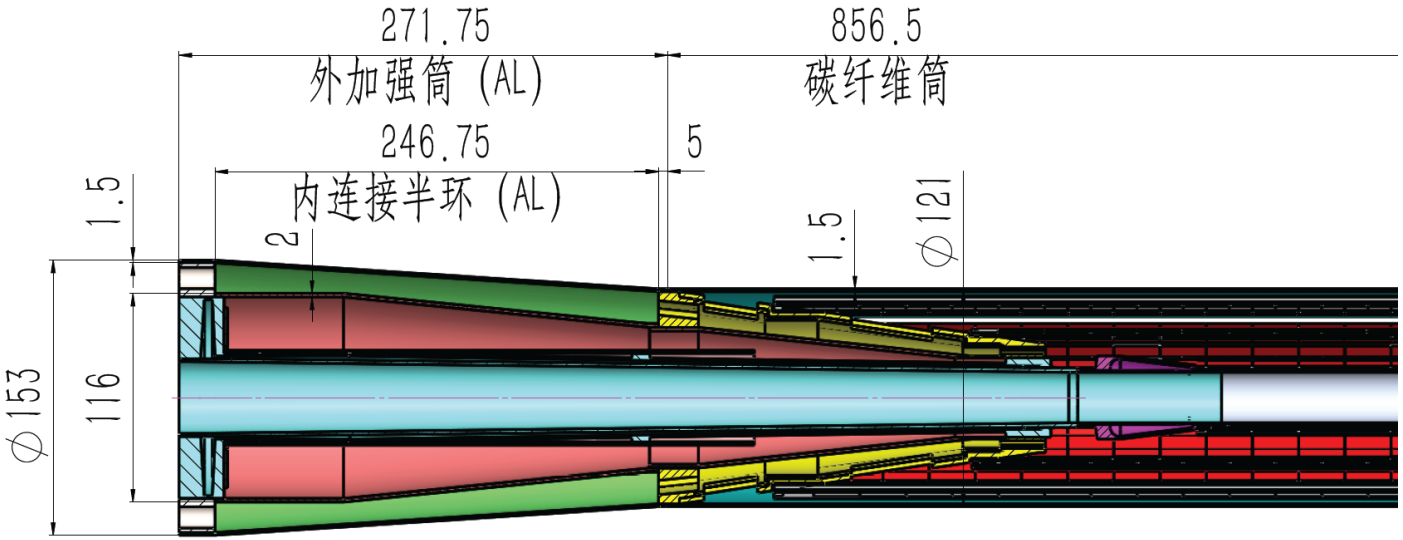
Summary：<u>the heat of vertex is removed by air cooling and remote cooling.</u>

4. Structure of Beam pipe （Ver.20200710）

4.6 External strengthen pipe

- The external strengthen pipe can form an air cooling channel and strengthen the whole structure.



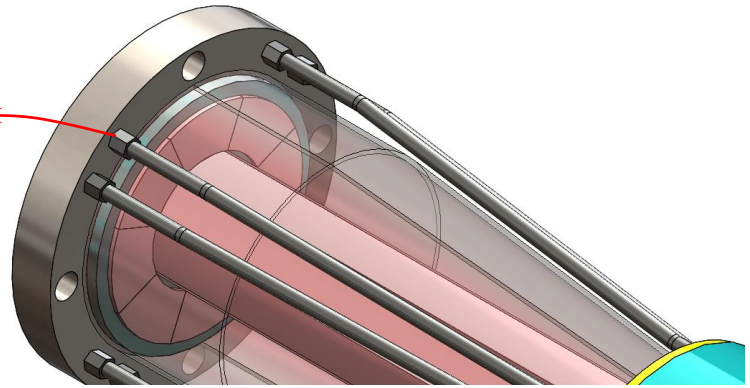


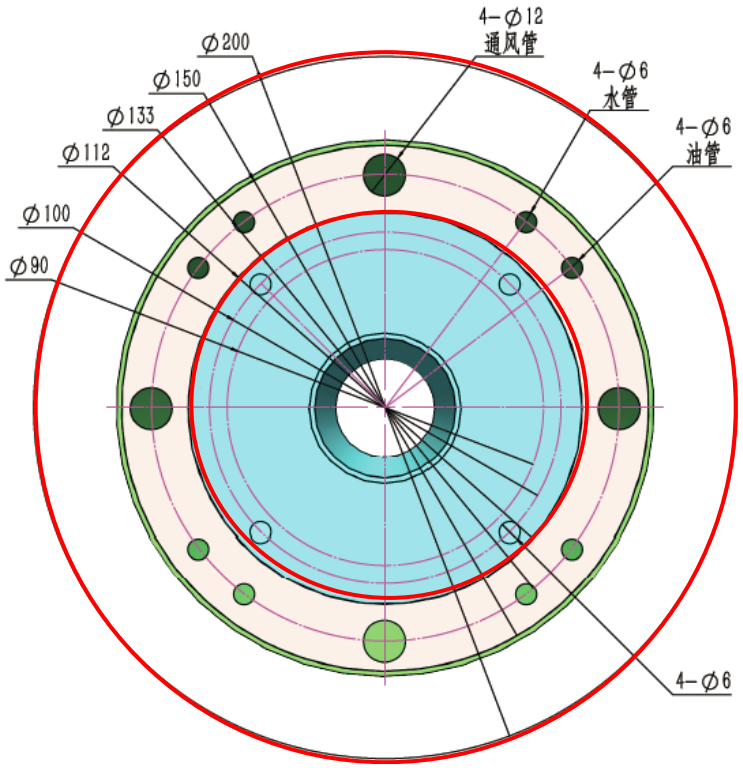
Summary： three-section design is convenient for detector and pipe installation, and convenient for carbon fiber tube processing.

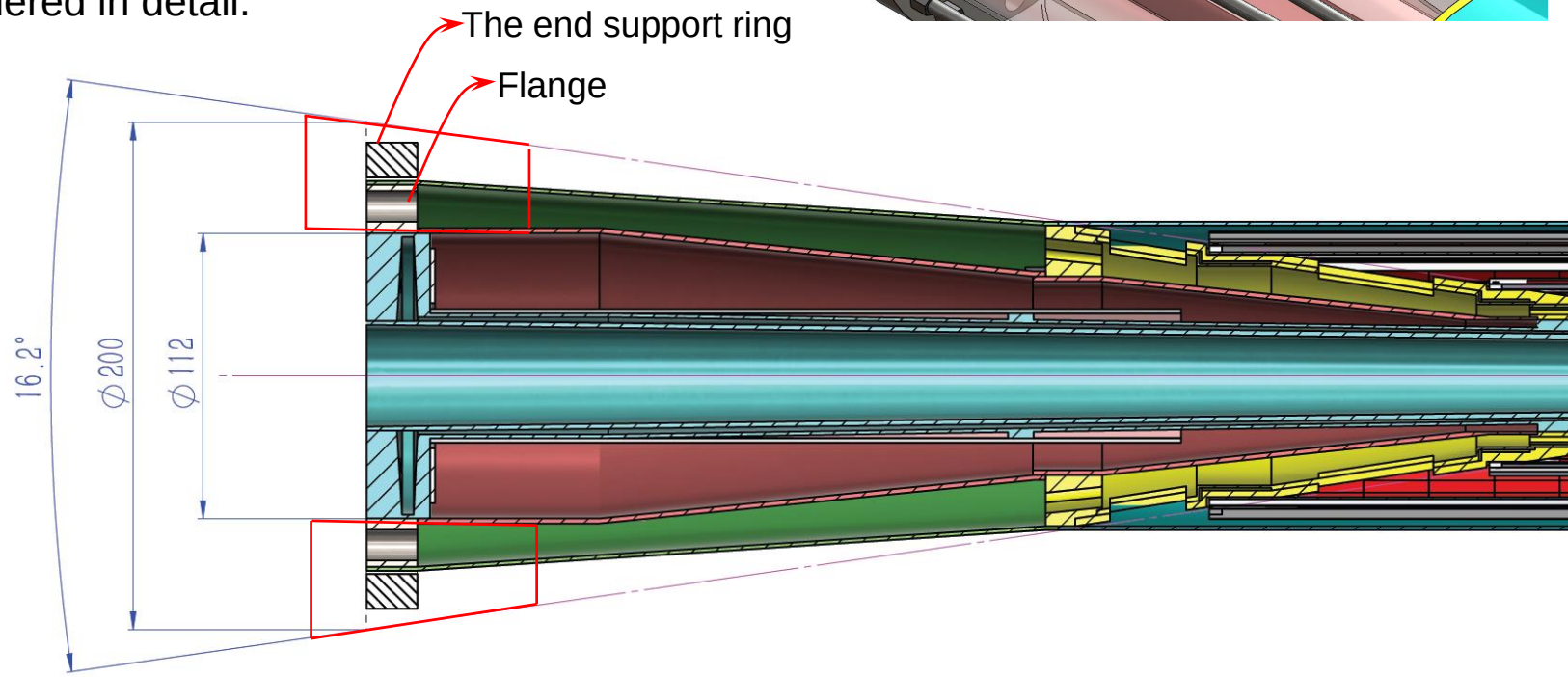
4. Structure of Beam pipe （Ver.20200710）

4.7 Flange

- All air pipe、 water pipe、oil pipe and cables can only go out through the area between Ø 112 and Ø 200 , the space is very small.
- As the detector and cable connector types are not clear, the cable extraction scheme has not been considered in detail.







Difficulty：Due to the compact space, it is difficult to extract all cables from the end flange.

5. Detector installation interface

5.1 Carbon fiber bracket for vertex

- All carbon fiber bracket are fixed on supporting pipe, and the supporting ends are located outside the detection angle.
- **Disadvantages:** The length of the vertex support is longer than the chip required for physical 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	

The length between the supporting points R

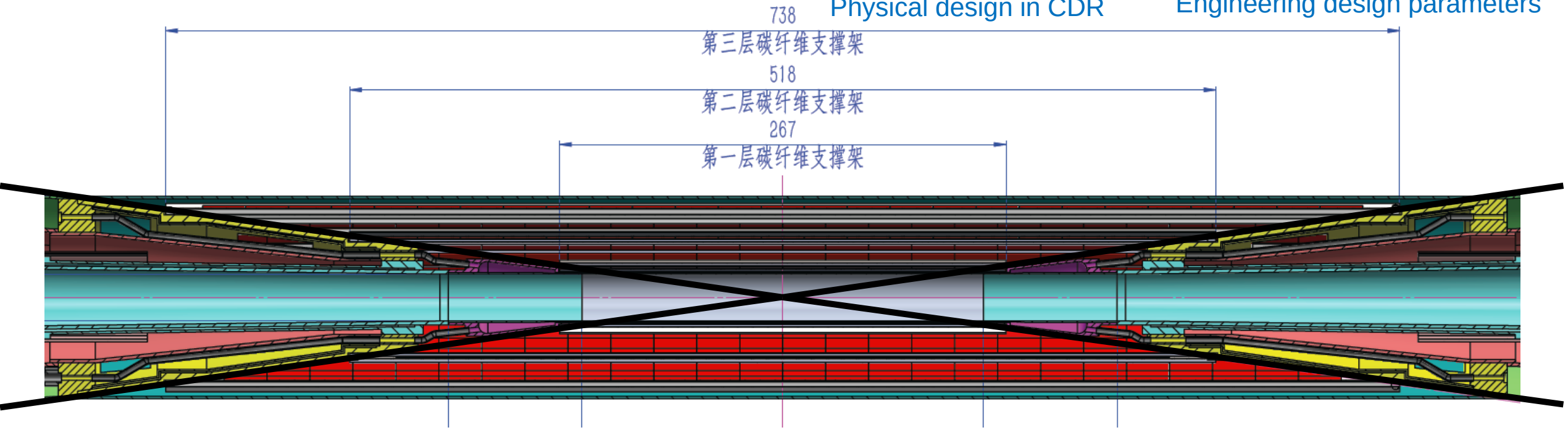
<< 267 16.5

<< 518 33.0

<< 738 47.5

Physical design in CDR

Engineering design parameters

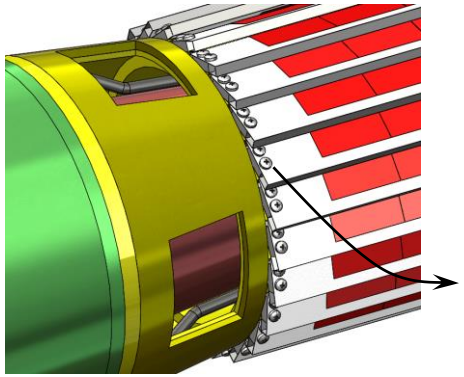


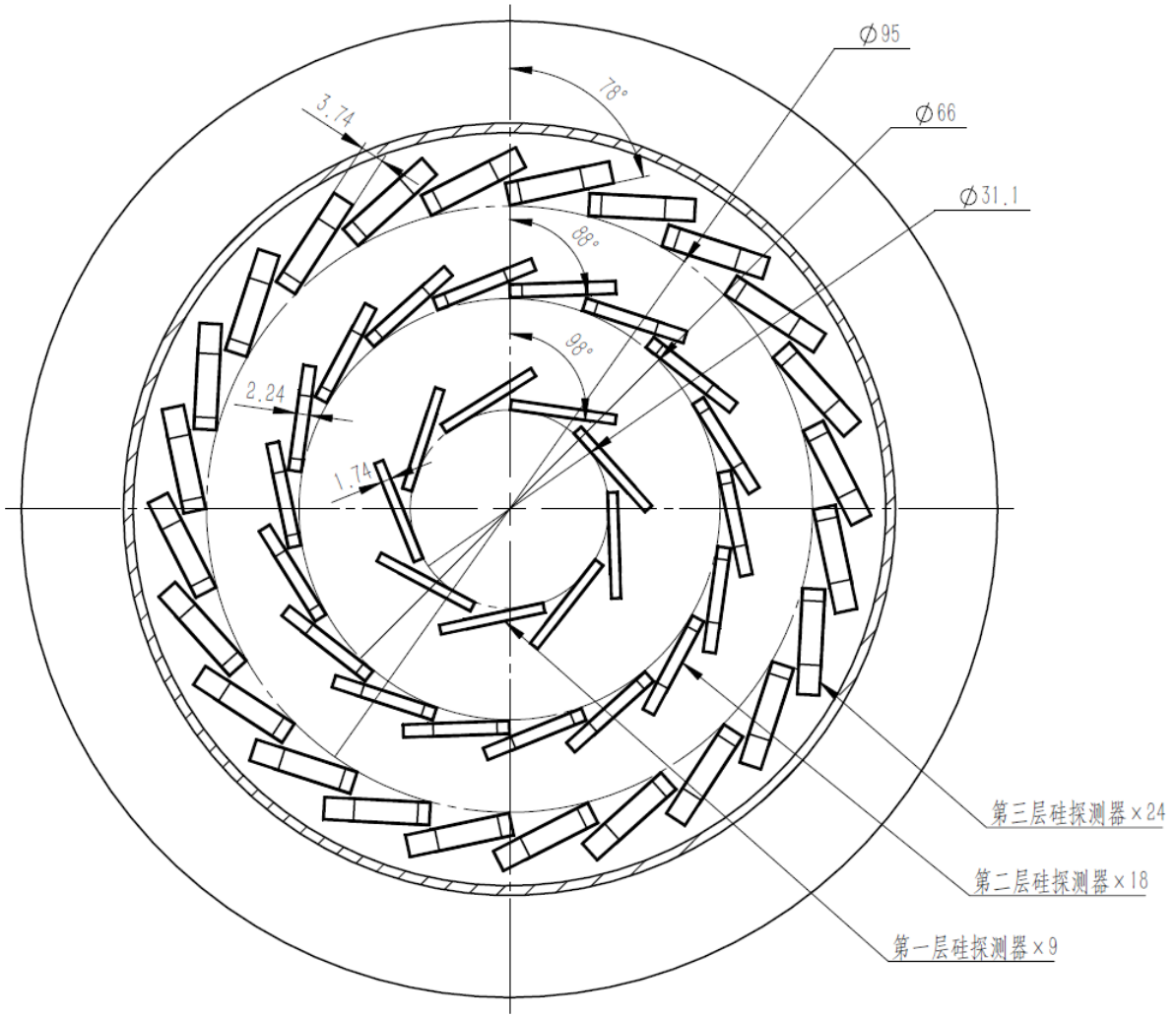
Summary：<u>The supporting structure provides very little mass.</u>

5. Detector installation interface

5.2 The distribution of Carbon fiber bracket for vertex

- The first layer: 9×vertex support，the Second layer：18×Vertex support，the third layer：24 ×Vertex support.
- Both ends of the carbon fiber vertex support are fixed on the supporting tube by screws.

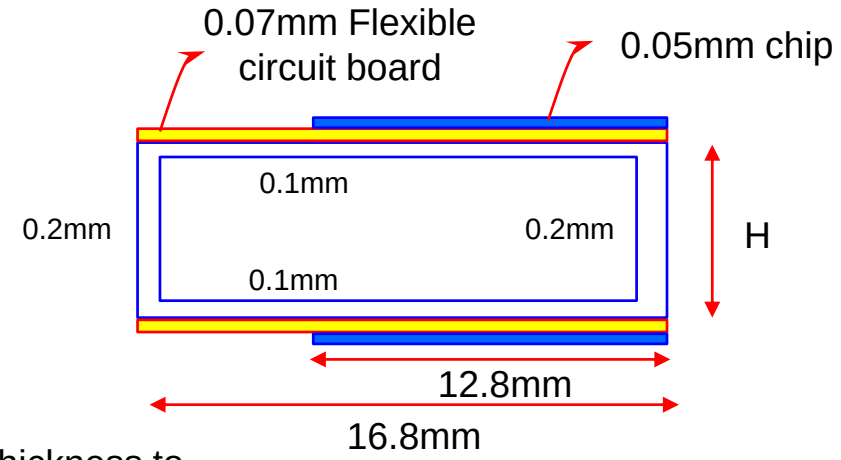




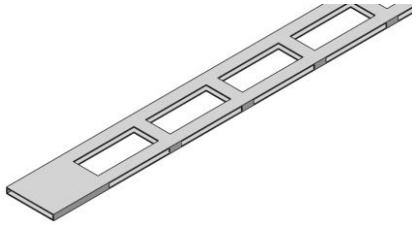
5. Detector installation interface

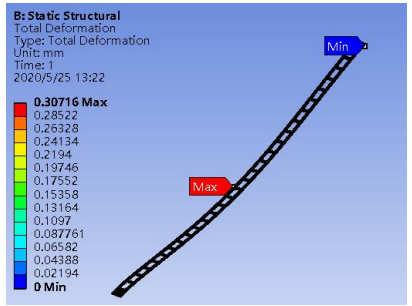
5.3 Optimize the structure of carbon fiber bracket

- Double-sided silicon chip, single thickness: 50 micron silicon chip +70 micron flexible circuit board +100 micron carbon fiber;
- Optimize the structure of carbon fiber bracket, match the beam tube design.

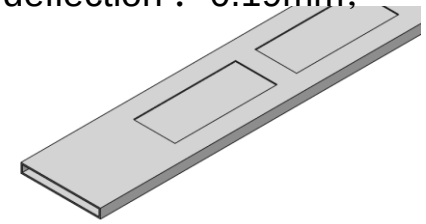


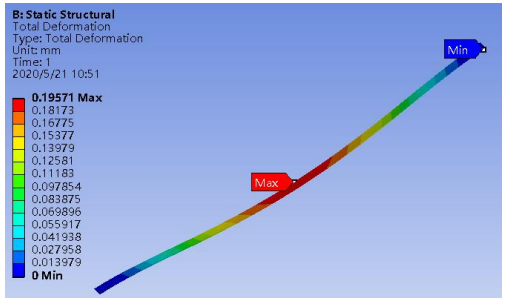
(1) Hollow carbon fiber，deflection：0.31mm；



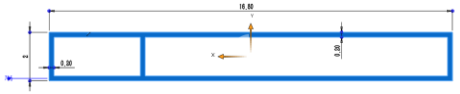


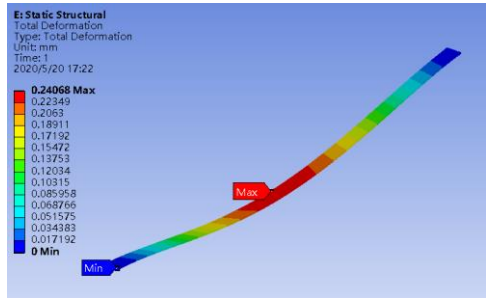
(2) Thin carbon fiber，deflection ：0.19mm；



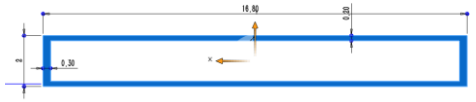


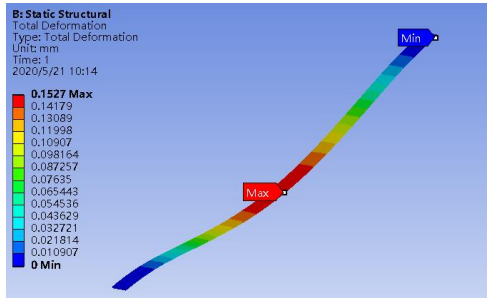
(3) Carbon fiber tube reinforcement，deflection ：0.24mm；



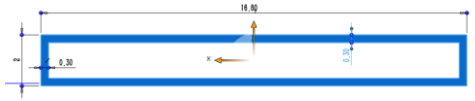


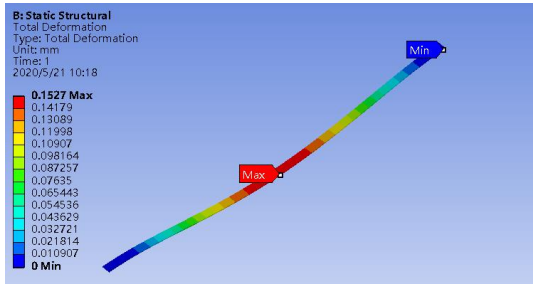
(4) Change wall thickness to 0.2， deflection ：0.15mm；





(5) Change wall thickness to 0.3，deflection ：0.15mm；



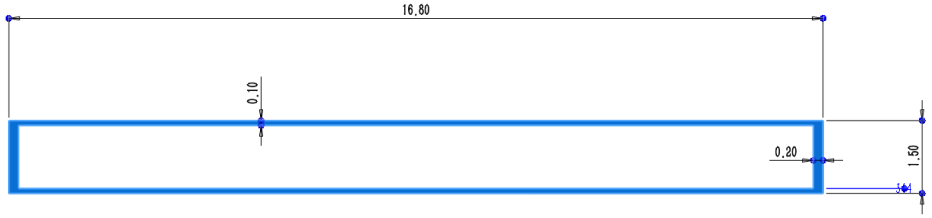


Summary：When the width is unchanged at 16.8mm, the deflection of the carbon fiber support can be reduced only by increasing the height.

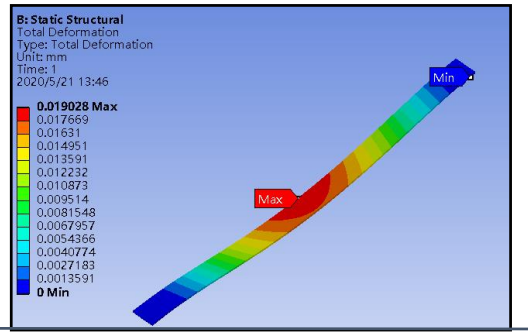
5. Detector installation interface

5.4 Recommended size of carbon fiber bracket

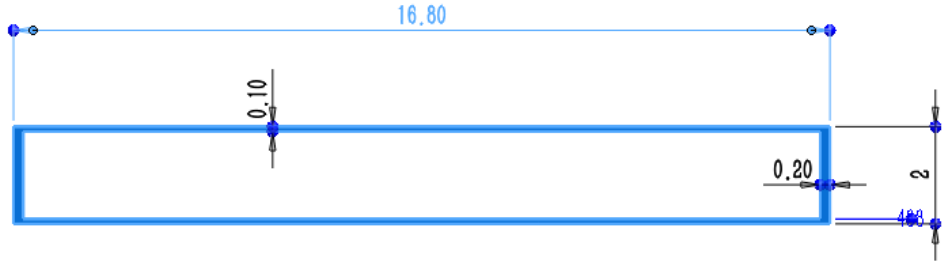
- The first layer，length:267mm，height：1.5mm；



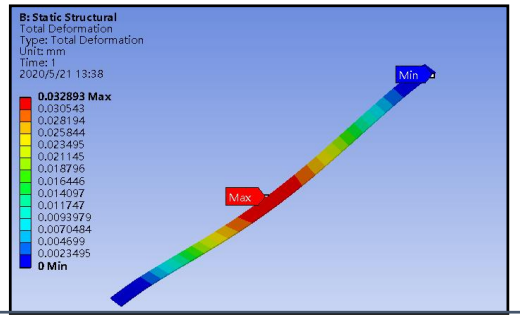
挠度：0.019mm



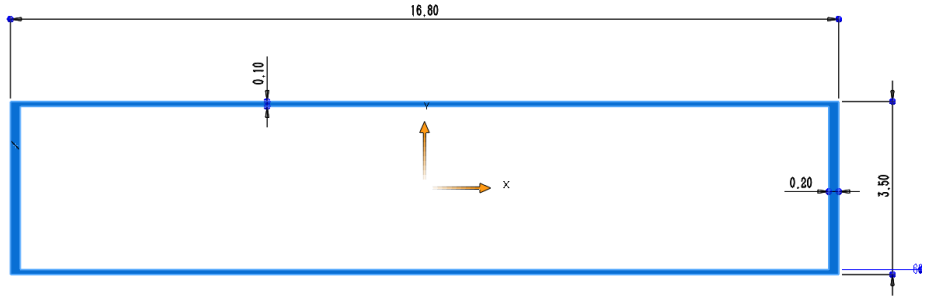
- The second layer，length:518mm，height：2mm；



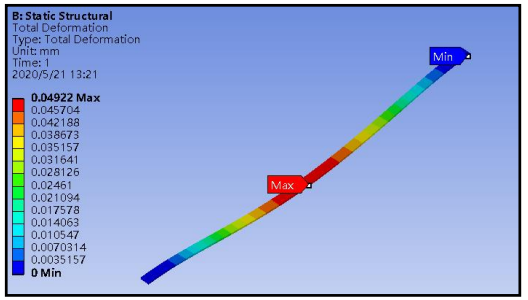
挠度：0.033mm



- The third layer，length:738mm，height：3.5mm；



挠度：0.049mm



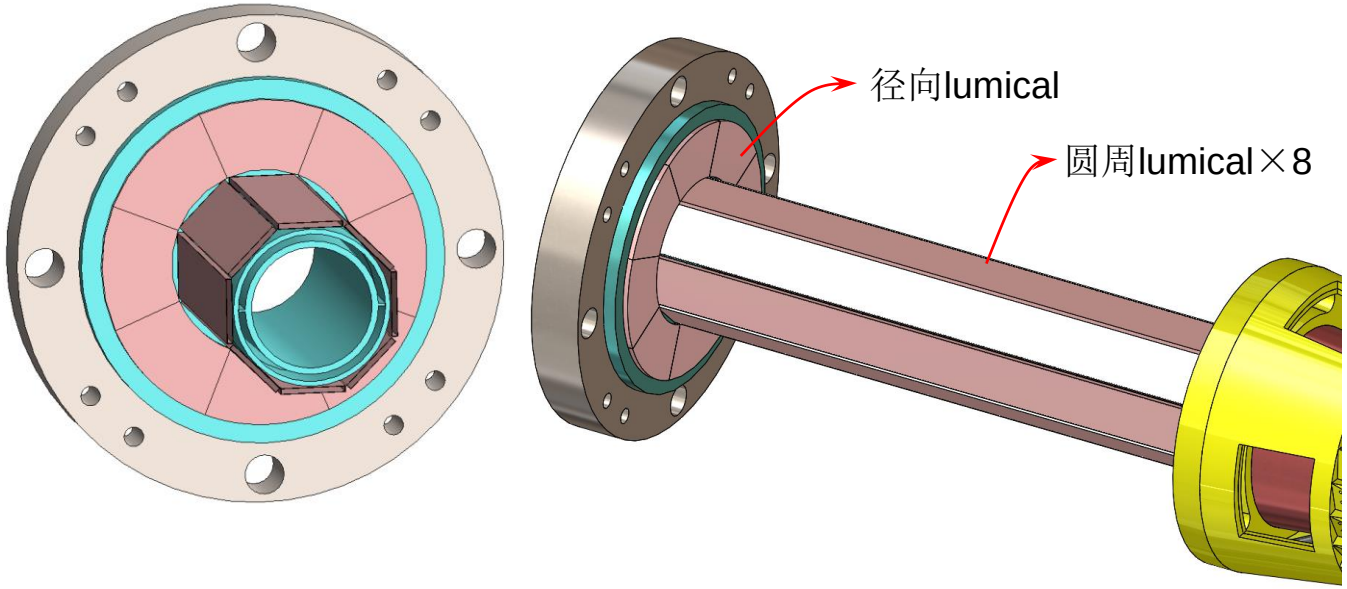
Summary: The recommended size of the carbon fiber bracket can match the current beam pipe structure.

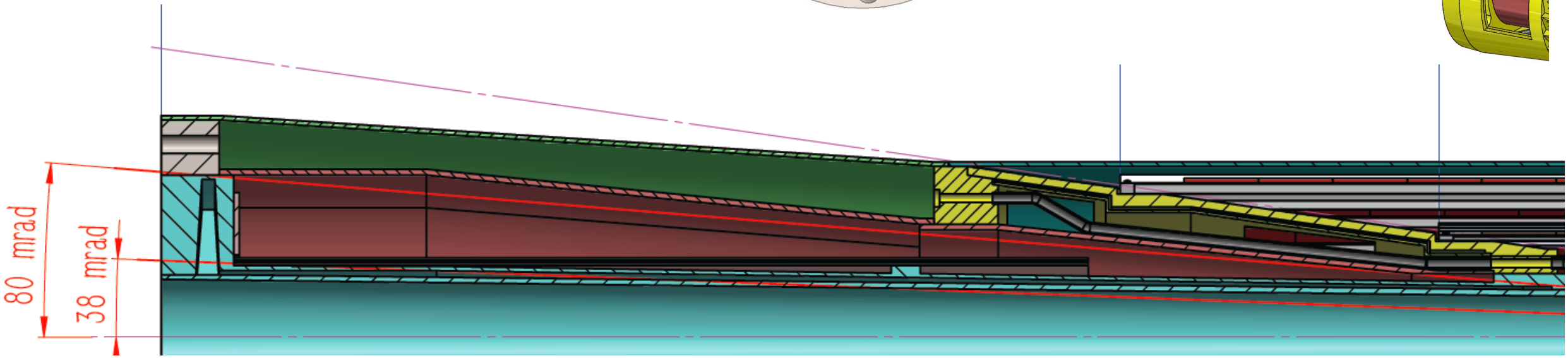
High thermal conductivity rectangular carbon fiber tube needs to be developed

5. Detector installation interface

5.5 Preliminary design of lumical

- Detection Angle range: 38~80mrad
- On the detection path, as little mass as possible
- The structure of lumical is not yet determined, so the support and cooling structure should be further optimized and improved.



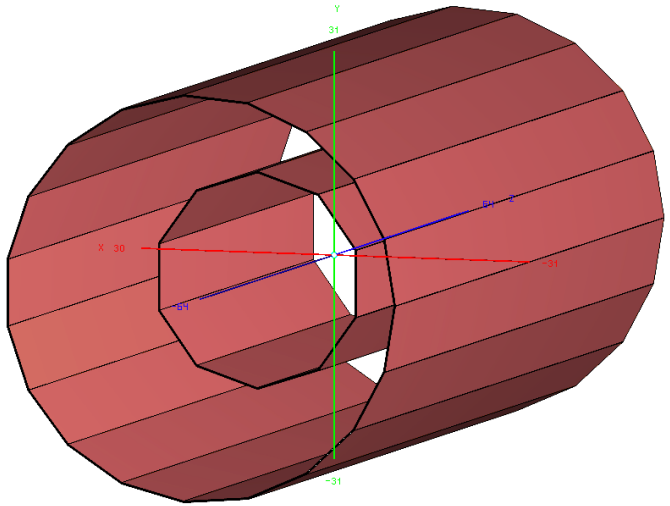


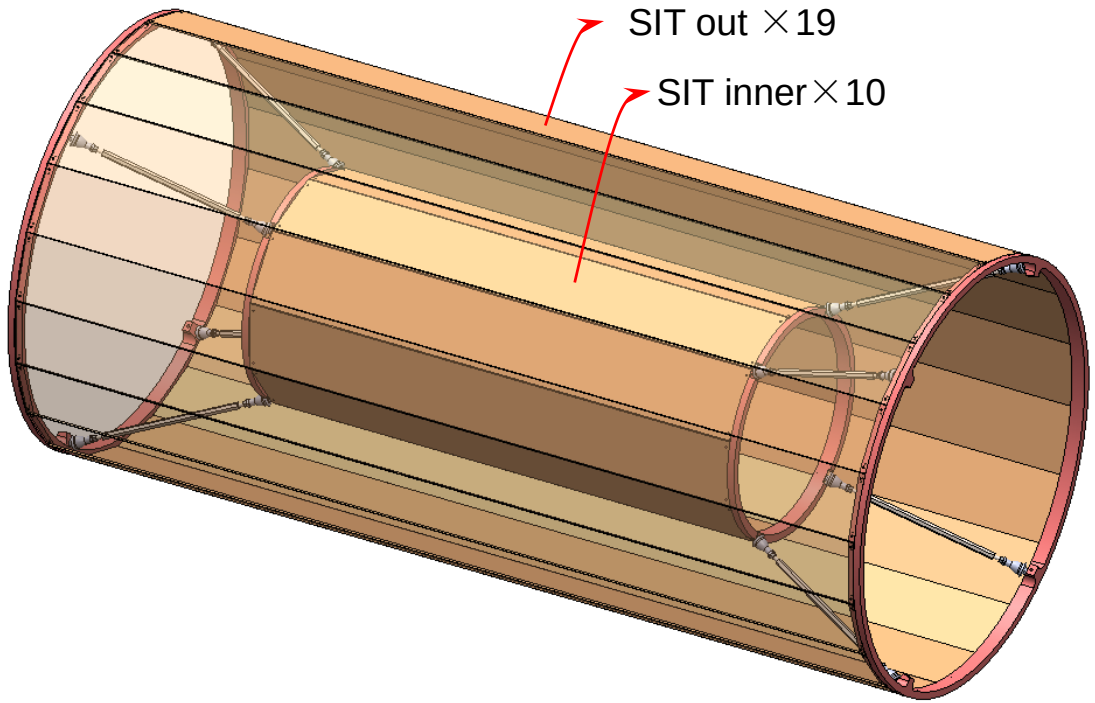
Summary：there is very little mass in the area of vertex detector angle.

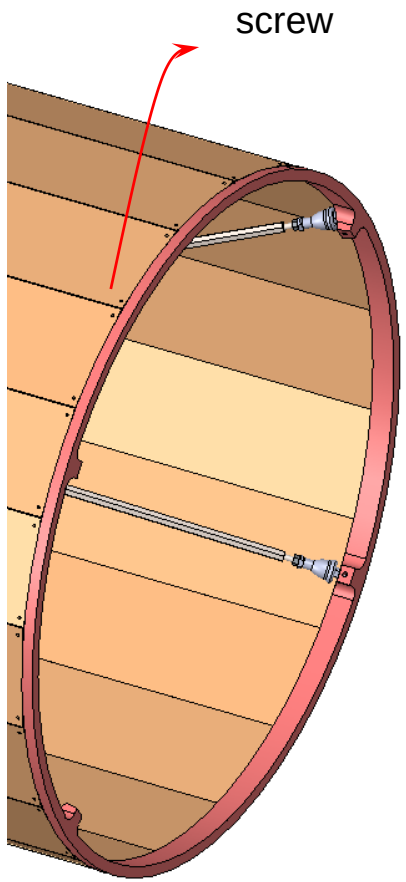
5. Detector installation interface

5.5 Preliminary design of SIT

- The detailed structure of SIT has not been designed.
- The inner end ring and outer end ring are designed for the SIT support.
- SIT outer end ring and SIT inner end ring are tensioned by four sets of adjusting rods
- Pipeline and cable extraction scheme has not been considered now.







The size of SIT (CDR)：

内筒10边形，内切圆外半径155.6mm，长度 736

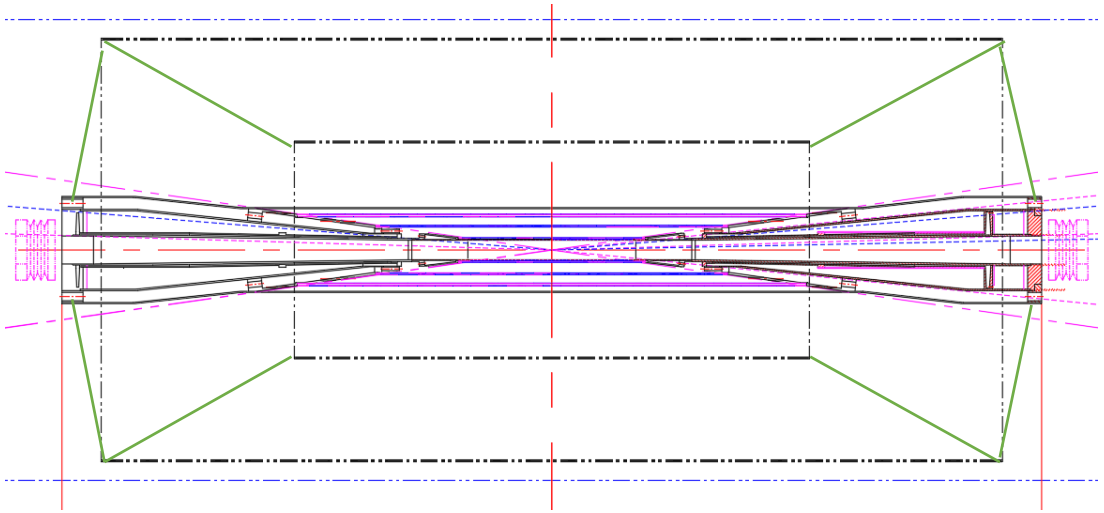
厚度：1.2+1.2+0.3

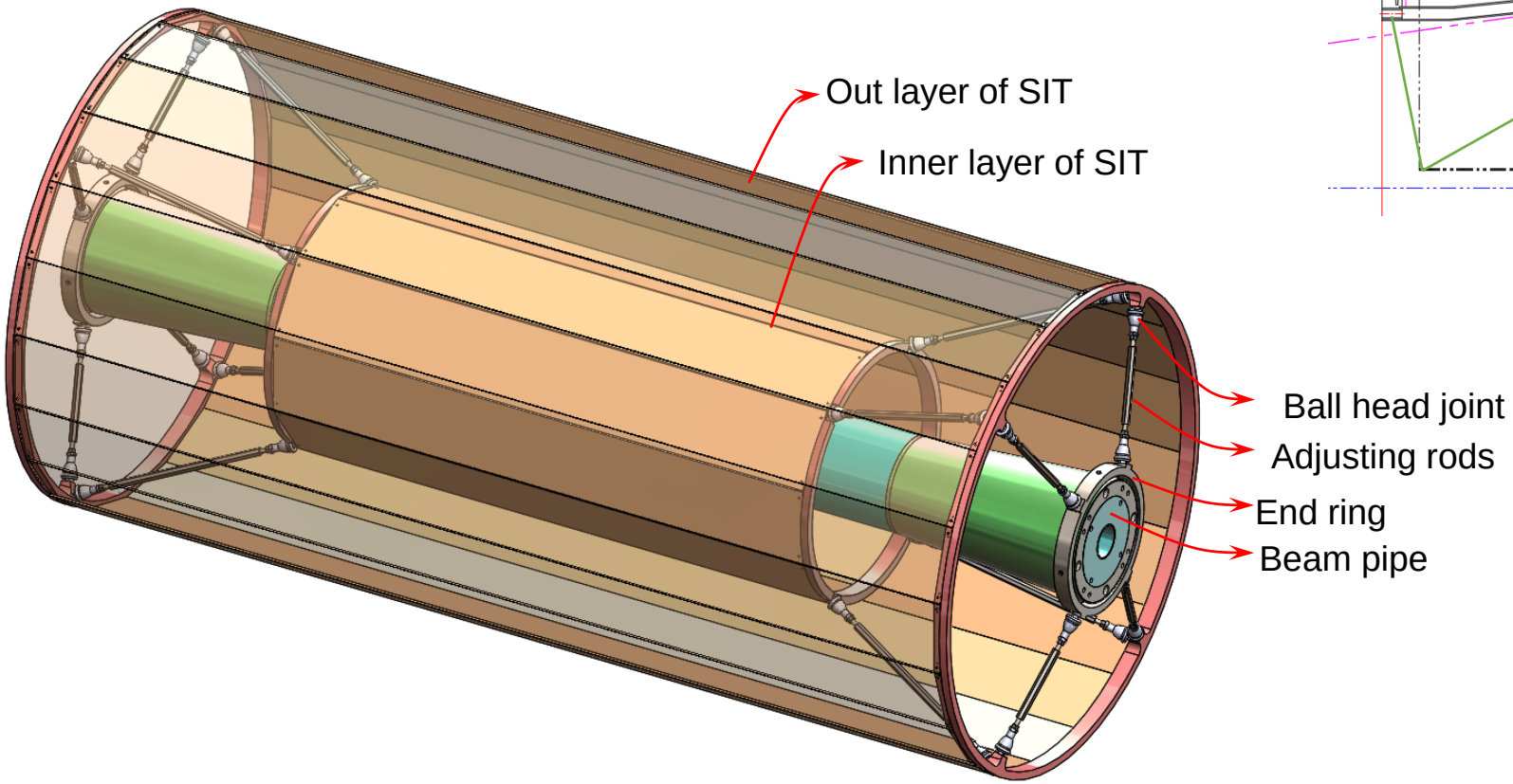
外筒19边形，内切圆外半径302.5mm，长度1288

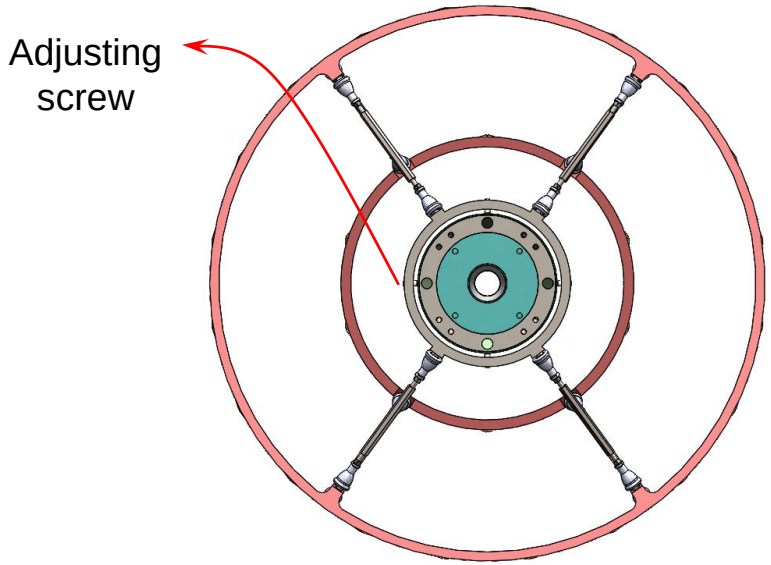
厚度：1.2+1.2+0.3

6. Connection structure between Beam pipe and SIT

- The outer end ring of SIT and the end ring of beam pipe are tensioned by four sets of adjusting rods；
- The space position of the beam pipe can be adjusted by four adjusting screws on the end ring of beam pipe；







Summary：The rod structure is simple, reliable and easy to adjust.

Existing problem: the supporting structure and cable joints are located in the detection Angle.

7. Summary and next plan

Summary of the latest structure：

- After several versions of iteration, the latest version can basically meet the detector support and cooling requirements.
- The inner wall of beam pipe are cooled by oil cooling and water cooling.
- Vertex are cooled by air cooling and remote cooling.
- The detailed interface structure of Vertex, Lumical and SIT needs further communication and improvement.

Next plan：

1. Outlet design for vertex cable.
2. The interface design of Lumical.
3. The interface design of SIT.
4. The beam pipe structure continues to be optimized with the optimization of the physical design.

Thank you for your attention