Mechanical design of VTX and OTK detectors for CEPC RTDR

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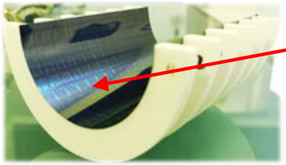
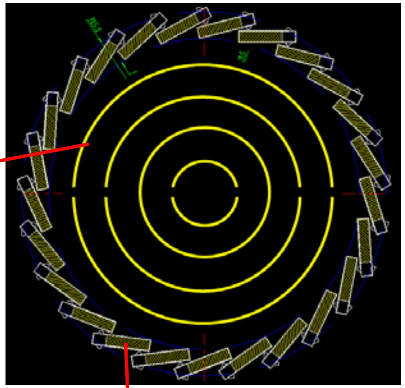
1. Silicon Vertex detector (VTX)

New baseline design: stiching (bent MAPS) + ladder MAPS

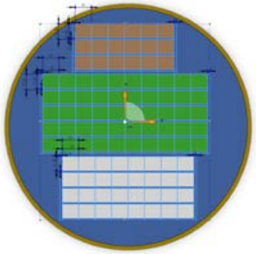
Layout : 4 single layer of bent MAPS + 1 double layer ladder MAPS

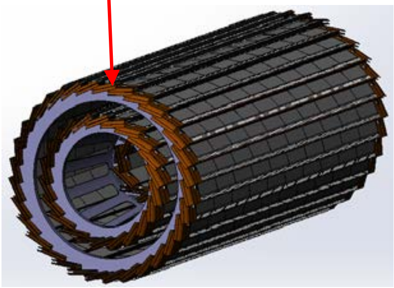
- Use single bent MAPS for Inner layers
  Low material budget per layer
- Ladder design for outer layer
  No dead area in ladder design





layer	Radius	Material
Layer 1	11mm	0.06% X0
Layer 2	16.5mm	0.06% X0
Layer 3	22mm	0.06% X0
Layer 4	27.5mm	0.06% X0
Layer 5/6 (Ladders)	35-45mm	0.5% X0
Total		0.74% X0

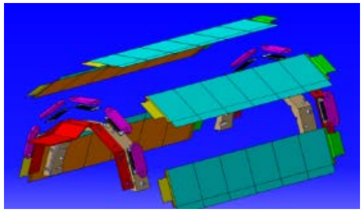


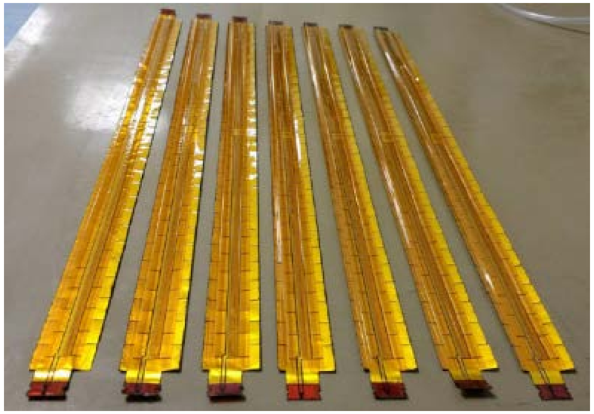


Challenge

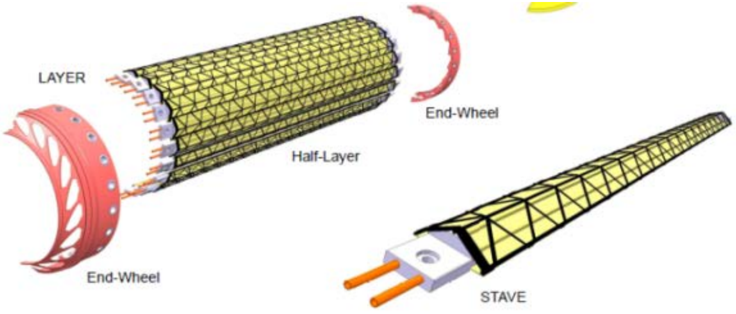
The big challenge: low material, high rigidity

Mu3e
0.1% X/X_0





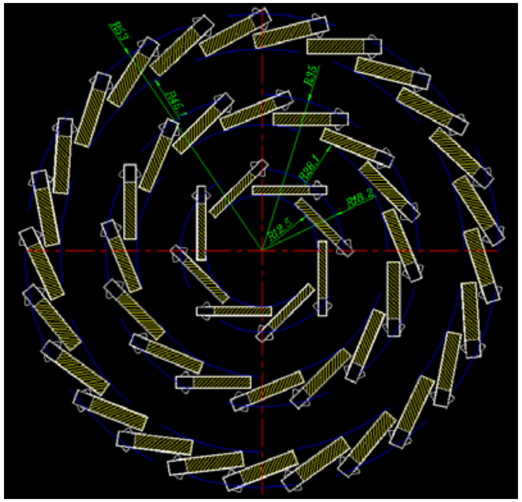
Alice ITS Upgrade
0.3% X/X_0



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

VTX design - Ladder MAPS

The VTX - section view



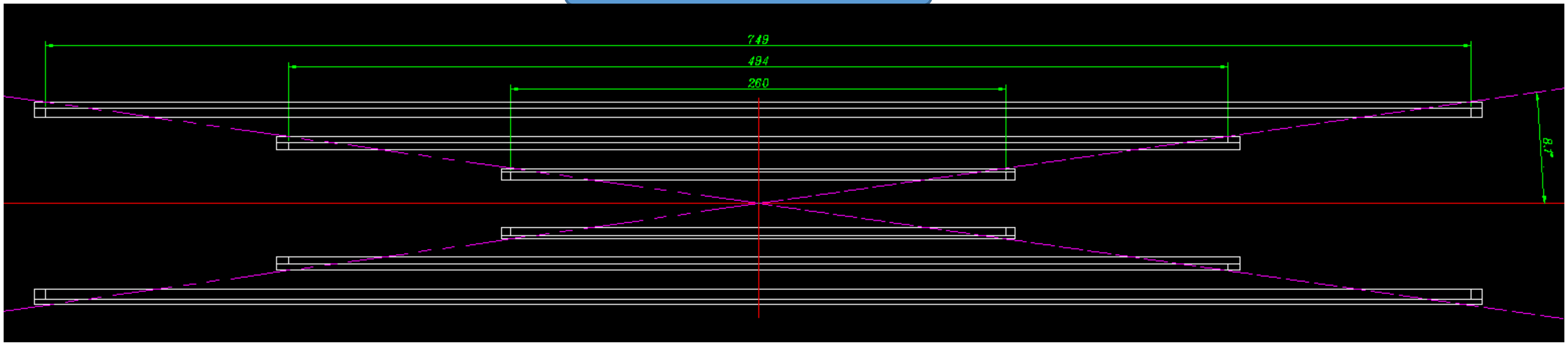
Three different sizes of ladders (section and length) for 3 barrels.

Only one layer of barrel will be employed in the new base design.

Ladder support

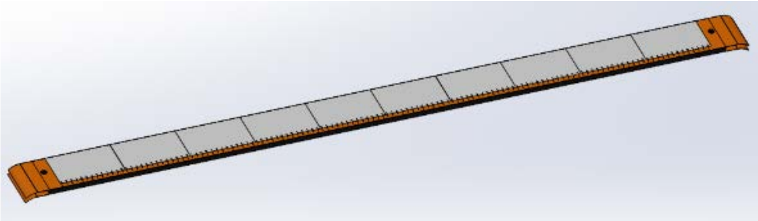
layer	Size .mm (W x H x L mm)
inner	17.4x1.7x260
middle	17.4x2.5x486
outer	17.4x3.2 x749

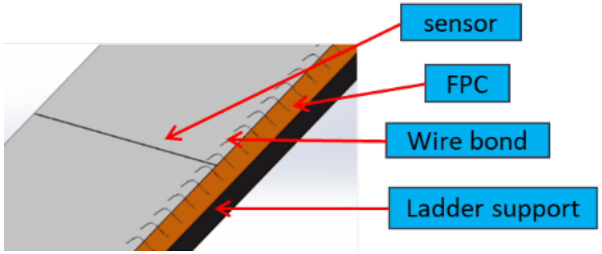
The VTX - side view



Ladder and support

Ladder components: similar to the CEPC VTX prototype

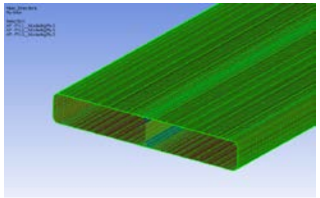


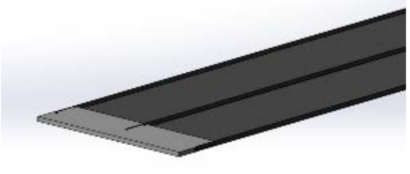


The max length of the ladder support is ~750 mm, about 3 times of that we made for the prototype.

The doable new sections design of such long CFRP ladder support (compared and confirmed):

- material selection - high modulus CFRP
- the maximum thickness of the stacked layers of plies 0.15 mm
- optimized ply angle design



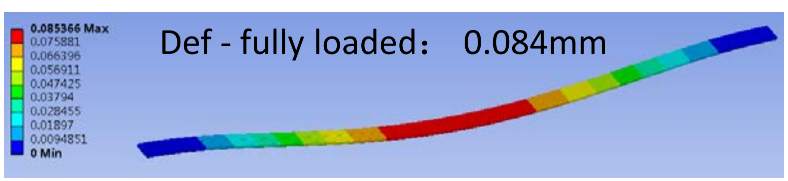


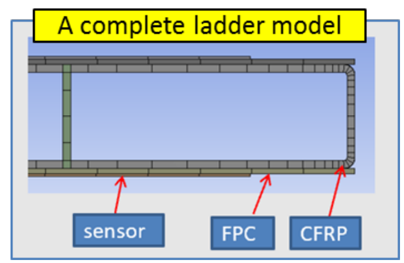
FEA of ladder support

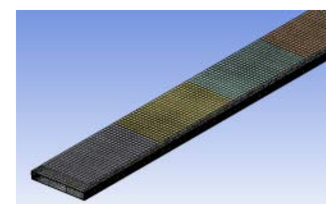
layer	Size .mm (W x H x L mm)	Thickness .mm (equivalent)	Max def .mm (Fully loaded)	Max def. mm (Self weight)
inner	17.4x1.7x260	0.167	0.019	0.006
middle	17.4x2.5x486	0.179	0.084	0.026
outer	17.4x3.2 x749	0.185	0.346	0.107

All ladder support resulted with acceptable deformation and very low IRF (<0.02) under full load.

Results of the middle layer ladder support

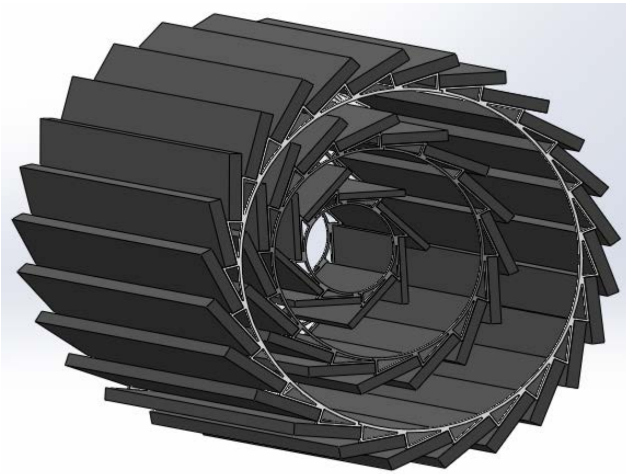




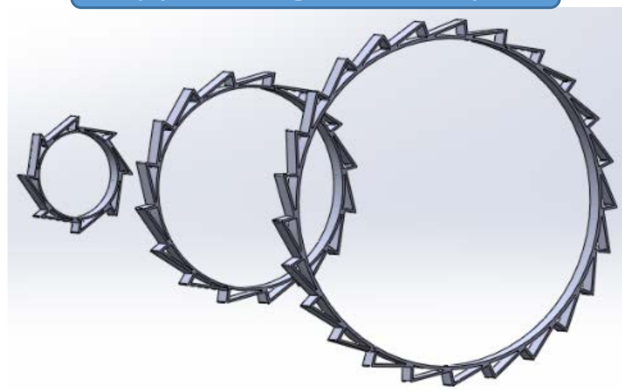


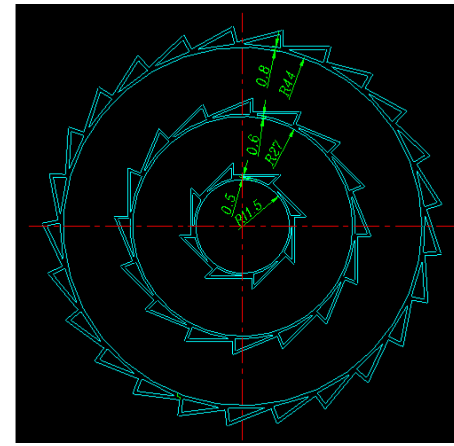
Previous FEA of the VTX prototype showed that a complete ladder deforms 20% lower than the bare ladder-spt under full load.

VTX assembly



Support rings / Al alloy

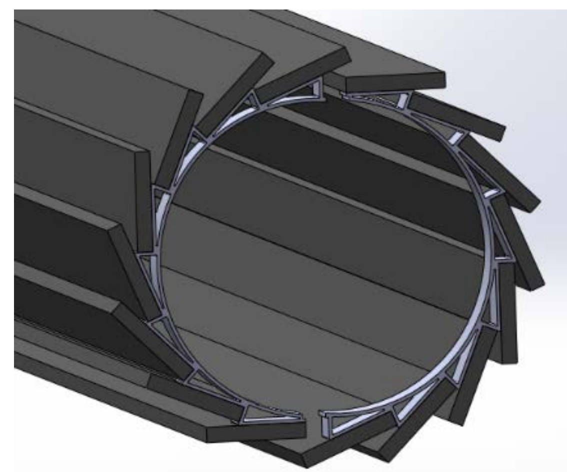




Ladder can be bolted to the support ring. Gluing allows hollow ratchet teeth, which helps ventilation, preferred for the inner layer.

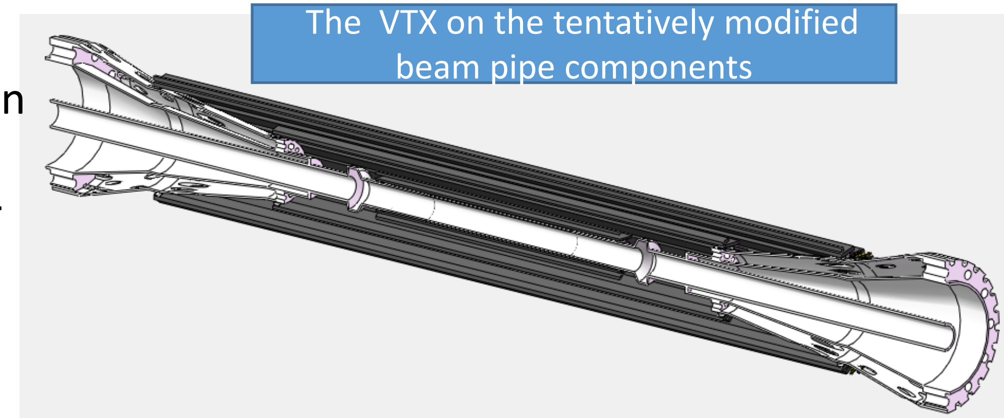
Two methods to assemble the VTX:

- Assemble the half barrel, then install them on the beam pipe.
- Install (*or machined*) the support rings on beam pipe in advance, then install the ladders (preferred for inner most layer).



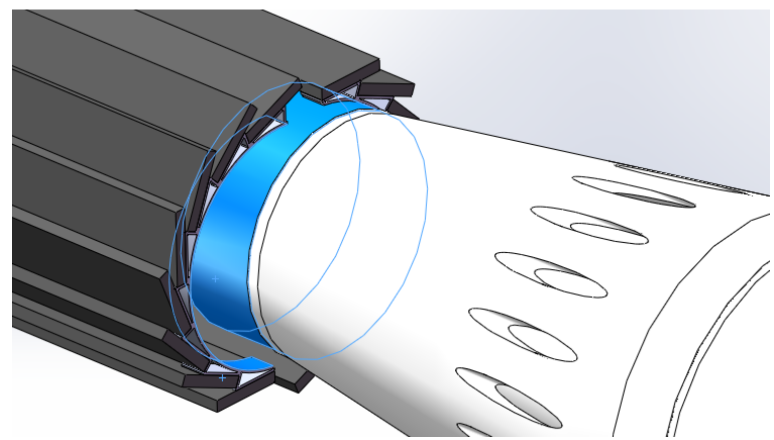
VTX installation on the beam pipe

The support ring can be either bolted/glued to or pre machined on the beam pipe related parts. (bolt connection is too difficult for inner layer)



The VTX on the tentatively modified beam pipe components

The option that pre-assembled halves of barrels mounted onto the beam pipe (dedicated tooling required)



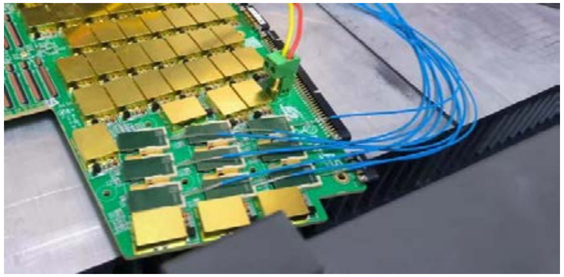
More consideration - different constraint on two ends?

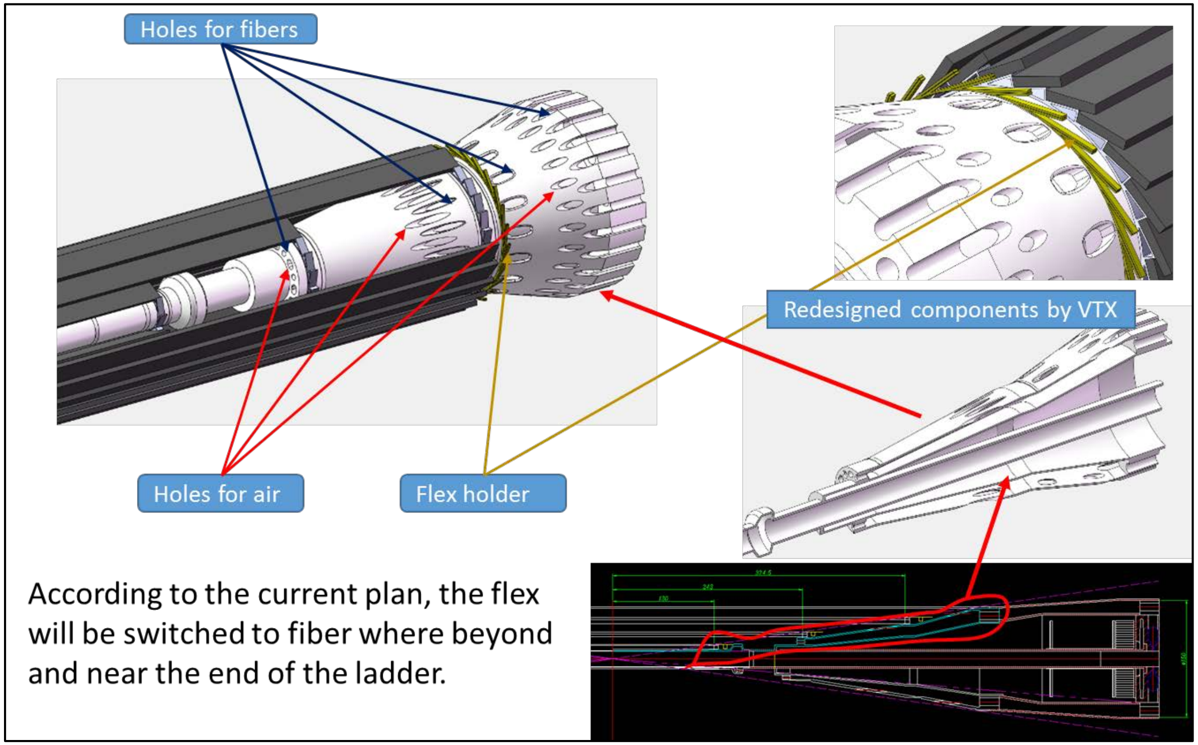
Air channels and cables routing

Limited space in MDI region for cable and service:

- All fast signal transferred into optical fiber in service region

Example from ATLAS HGTD upgrade





Cooling simulation of the ladder based barrel

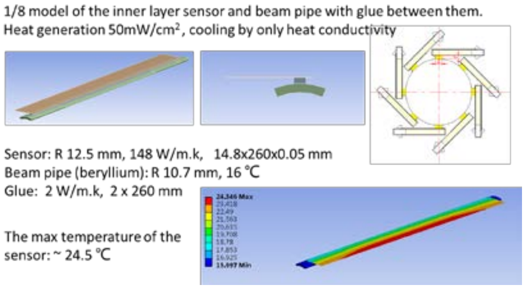
- Power dissipation: 50 /40/30 mW/cm2
- Total heat generation of the VTX: 421 /337/253 W
- Inlet air temperature 5 ℃
  (Beam pipe temperature not considered)

Layer of barrel	Chip coverage (mm)	Number of ladders	Heat generation-of barrels(W)	Simulation results the Max temp (Celsius)		
inner	14.8x260	8	27	82	66.6	51.4
middle	14.8x494	16	117	34.5	27.8	22.1
outer	14.8 x749	25	277	37.2	30.2	24

- Given 15 ℃ temperature change, the estimated air flow rate ~1.49 m3/min, equal to 2.3 m/s in barrels section. Cooling setup with lower flow rates were also tried but resulted with much higher temperature.

To cool the detector to 20 ℃ with a gradient less than 15 ℃, only air cooling seems can't satisfy the inner layer barrel (*1.9mm gap to beam pipe*).

- The solution to add thermal conductive glue between the detector and beam pipe was studied and thermal analysis shows optimistic results.



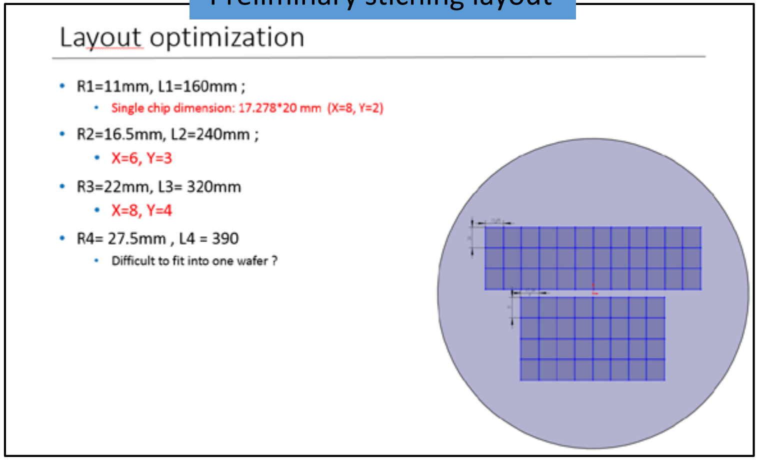
VTX structure - stiching technology based

- **4 single layer of bent MAPS structure**

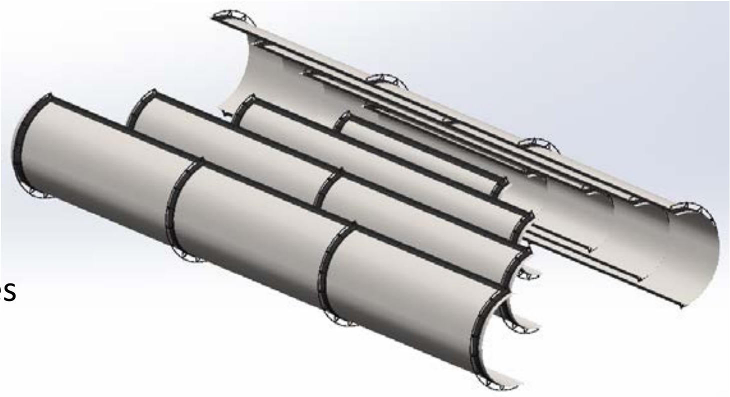
  Many mechanical related issues being discussed and to be studied:

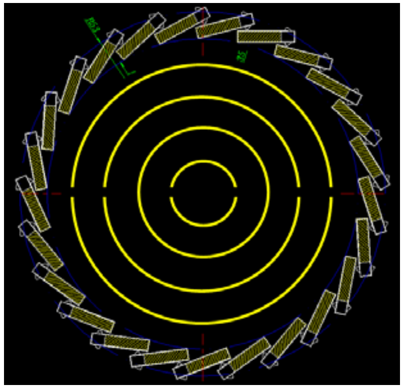
  - Wafer thickness VS bent radius
  - Wire bond and cable routing?
  - shape retaining and connection in Z direction
  - Ventilation of air cooling
  - Layers integration on the beam

Preliminary stiching layout



Preliminary structure design of the bent MAPS detector





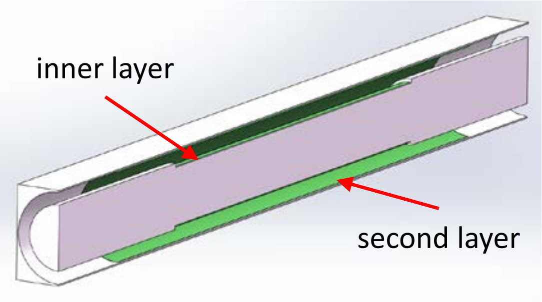
- one layer has two hemicycles
- low support materials
- more area for ventilation

Innermost layer cooling simulation

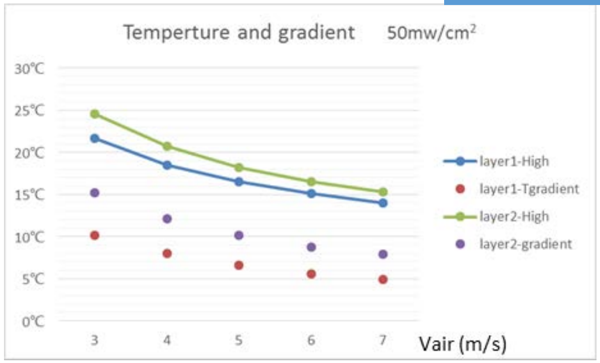
For the innermost layer (R=11mm), it is quite close to the beam pipe(R=10.7mm), the air cooling simulation has been conducted.

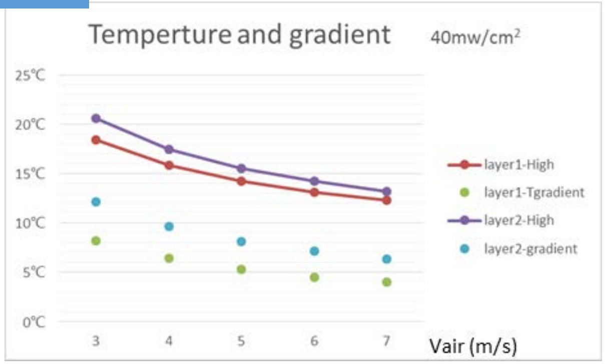
- Power dissipation: 50 mW/cm^2 , 40 mW/cm^2
- Inlet air temperature 5 ℃
- Inlet air velocity varys from 3 m/s to 7 m/s

(Second layer involved, beam pipe temperature ignored)

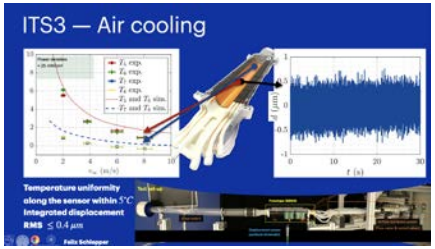


Simulation results





- To air cool the innermost layer detector within 20 ℃ seems feasible. *Temperature gradient should be controlled in a certain level from safety point view?*
- More to be studied !

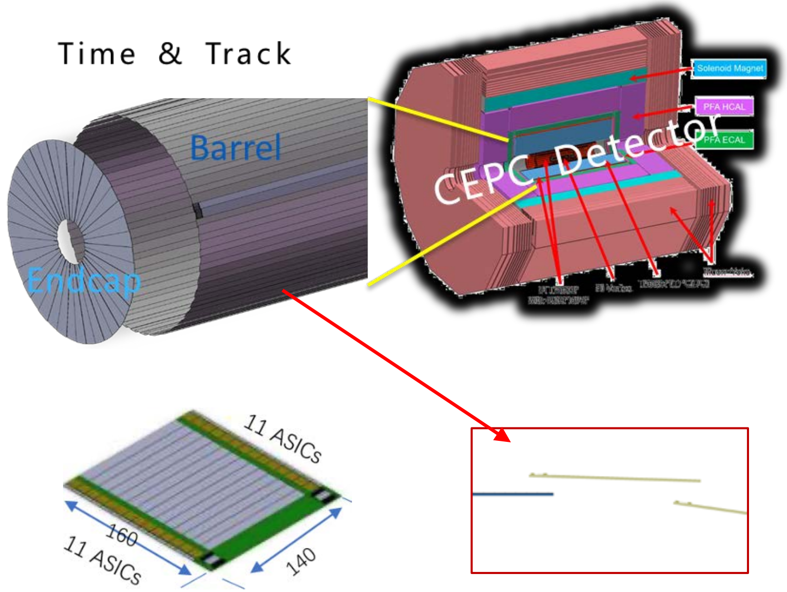


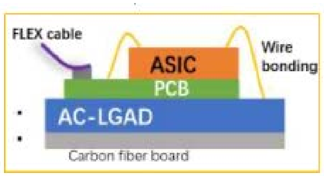
2. Silicon outer tracker detector (OTK)

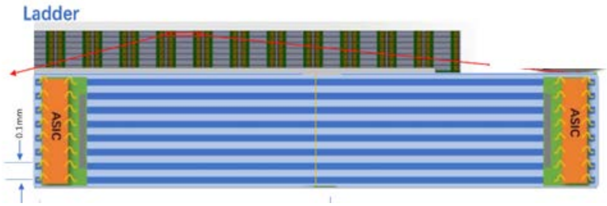
OTK Barrel

- one layer tracker detector/ToF ~70 m^2 ,
  3780 modules
- Rmin= 1800 mm, L=5800 mm
- 90 ladders, overlapped deployed
- Ladder: 160 x 5800（nominal） mm
    - 42 modules/ladder
    - 28 ASIC/module
    - 128 Channel/ASIC

LGAD based 4D timing detector-Reference TDR of CEPC



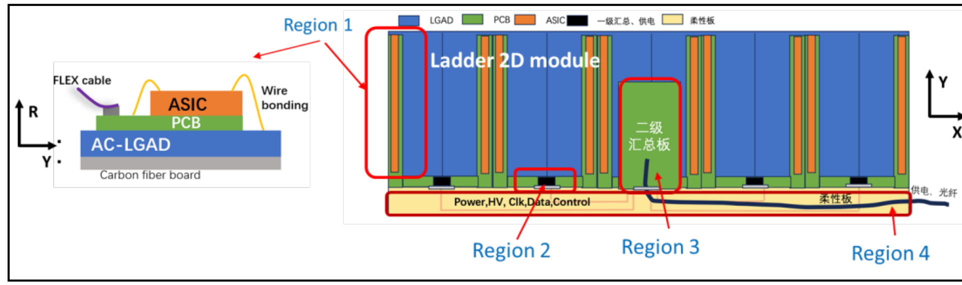




Ladder structure

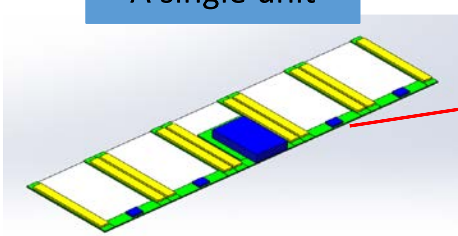
Detail thicknesses of different regions

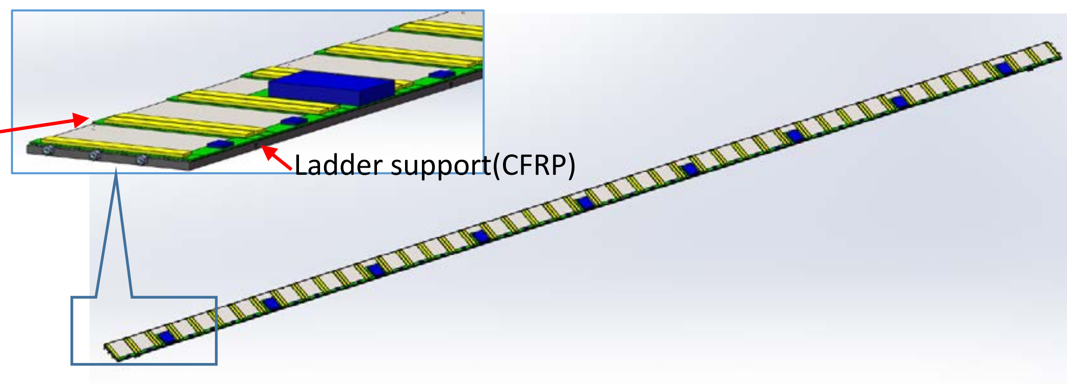
- The thickness of the region 1：4.6mm
  - ✓ PCB：1.6 mm
  - ✓ ASIC：3 mm
- The thickness of the region 2:
  - ✓ 一级汇总供电：3 mm
  - ✓ PCB：1.6 mm
- The thickness of the region 3：**14.6 mm**
  - ✓ 电源模块：6 mm
  - ✓ 光电复合电缆：5mm
  - ✓ 弯折走线空间：2mm
  - ✓ PCB：1.6 mm
- The thickness of the region 4：6 mm
  - ✓ 柔性板厚度：1 mm
  - ✓ 二级汇总电缆：5 mm（高低压供电，光纤）



The ladder /160 x 5800（nominal） mm

A single unit





Detailed Ladder structure will be further designed combing with the clear cooling scheme and simulation results.

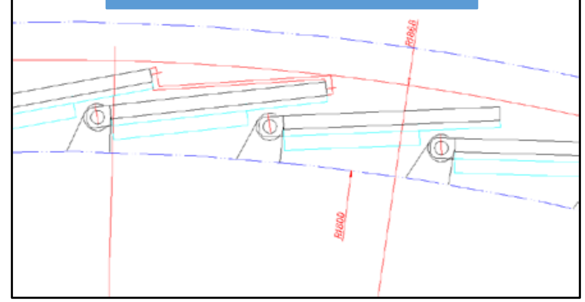
Ladder deployment optimization

Considering the ladder support and installation, electronics deployment and cooling structure, different ladder deployments were studied and compared.

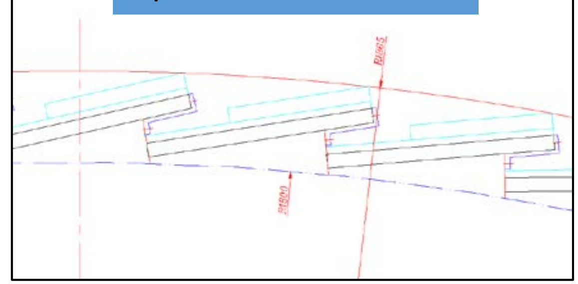
The best option:

- minimum space required in R direction ΔR=58 mm
- Sensors toward outside direction (update recently)

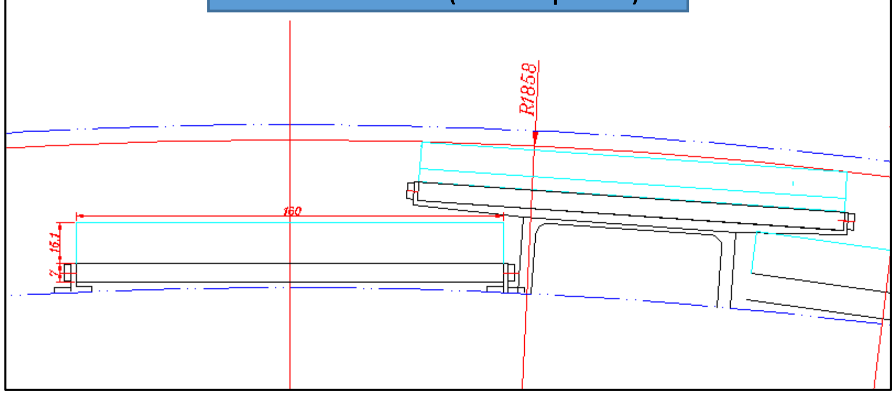
option2: ΔR = 68 mm



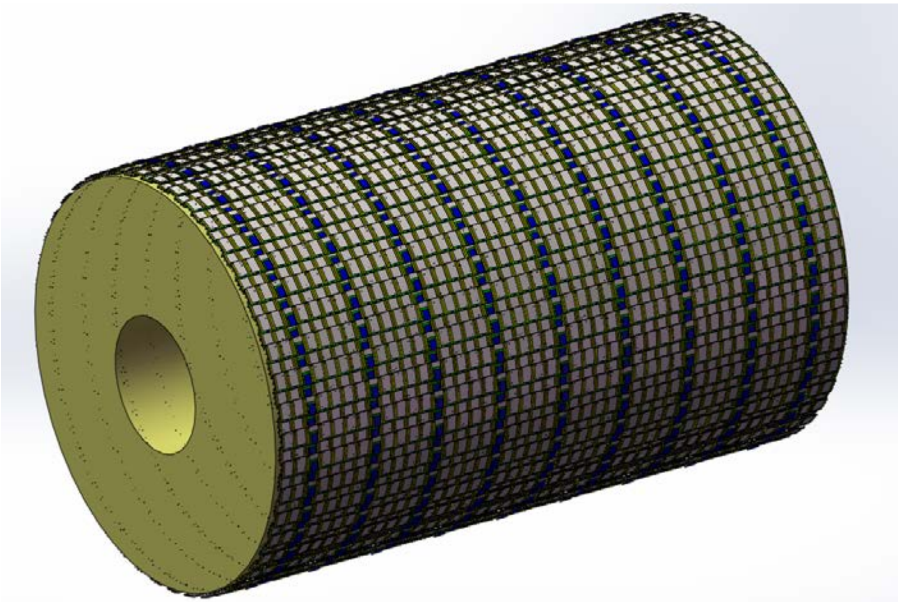
option3: ΔR = 65 mm

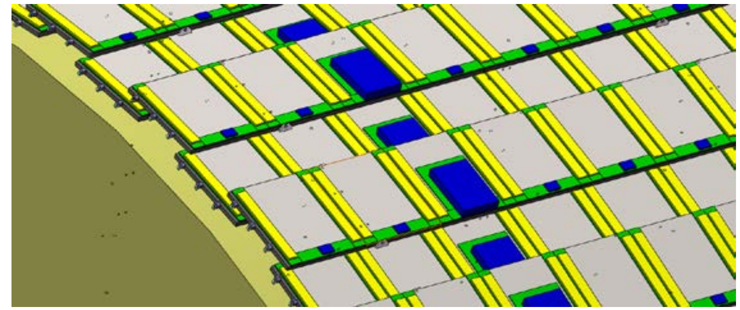


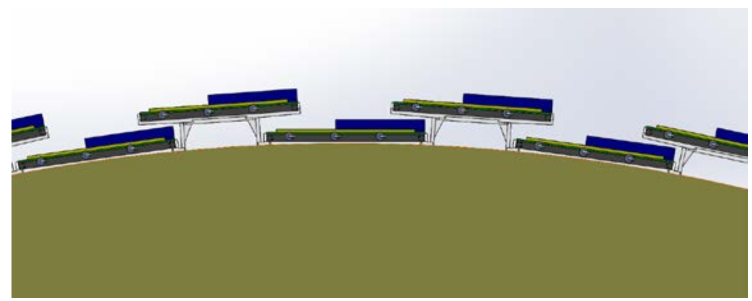
ΔR = 58 mm (Best option)

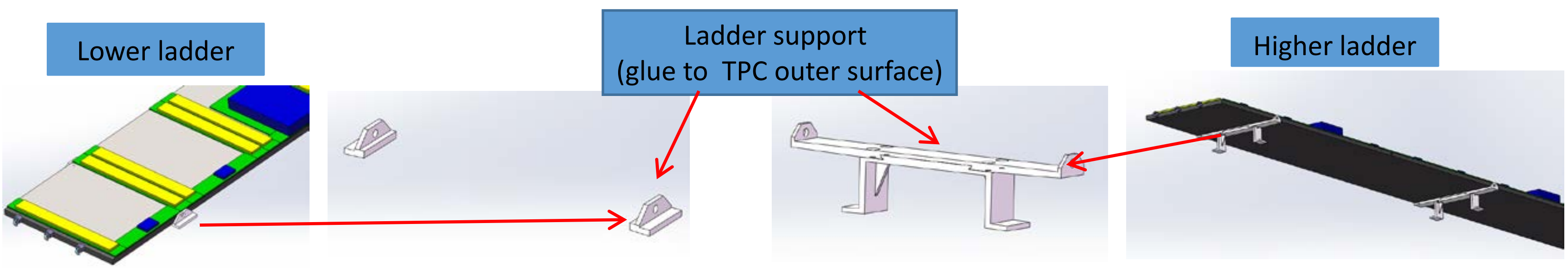


Preliminary OTK barrel structure









Thermal analysis of OTK ladder

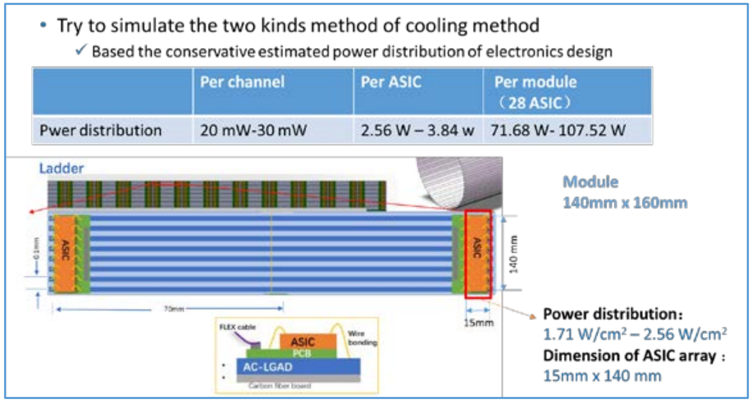
Thermal analysis with different cooling pipe deployments was carried out with two strategies:

- the cooling pipe on the ASIC side
- the cooling pipe on the ladder support side

ASIC Power: 35.84W (15x140x3 mm)
PCB t=1.6mm
LGAD t= 0.5mm
Materials:

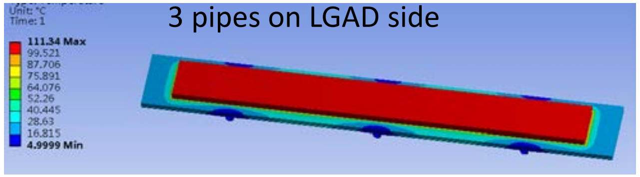
- Support -CFRP t=0.2
- Pipe - titanium
- LGAD, ASIC- silicon
- PCB

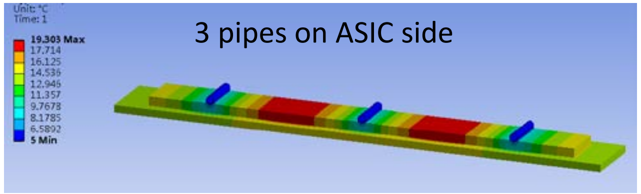
Cooling pipe 5℃

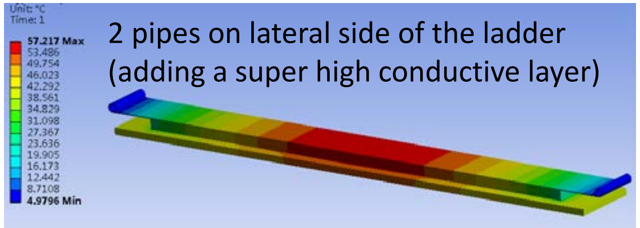


- Try to simulate the two kinds method of cooling method
  - ✓ Based the conservative estimated power distribution of electronics design

	Per channel	Per ASIC	Per module （28 ASIC）
Pwer distribution	20 mW-30 mW	2.56 W – 3.84 w	71.68 W- 107.52 W



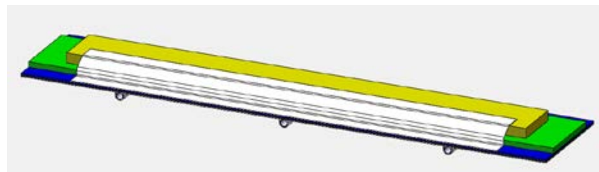


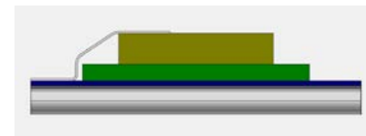


Pipes on the ASIC is much better than deployed on LGAD side, but hard to realize.

Thermal analysis of OTK ladder

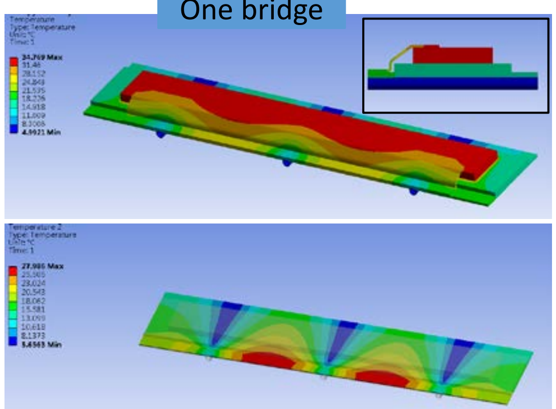
New optimized cooling scheme: add a thermal conductive bridge over the PCB to connect the ASIC and LGAD



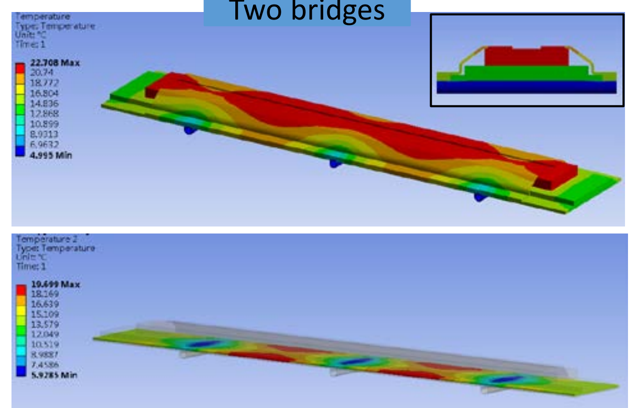


One bridge, 0.5mm Cu: ASIC~ 35 ℃， LGAD ~ 28 ℃
Two bridges, 0.5mm Cu: ASIC~ 23℃， LGAD ~ 20 ℃

One bridge



Two bridges



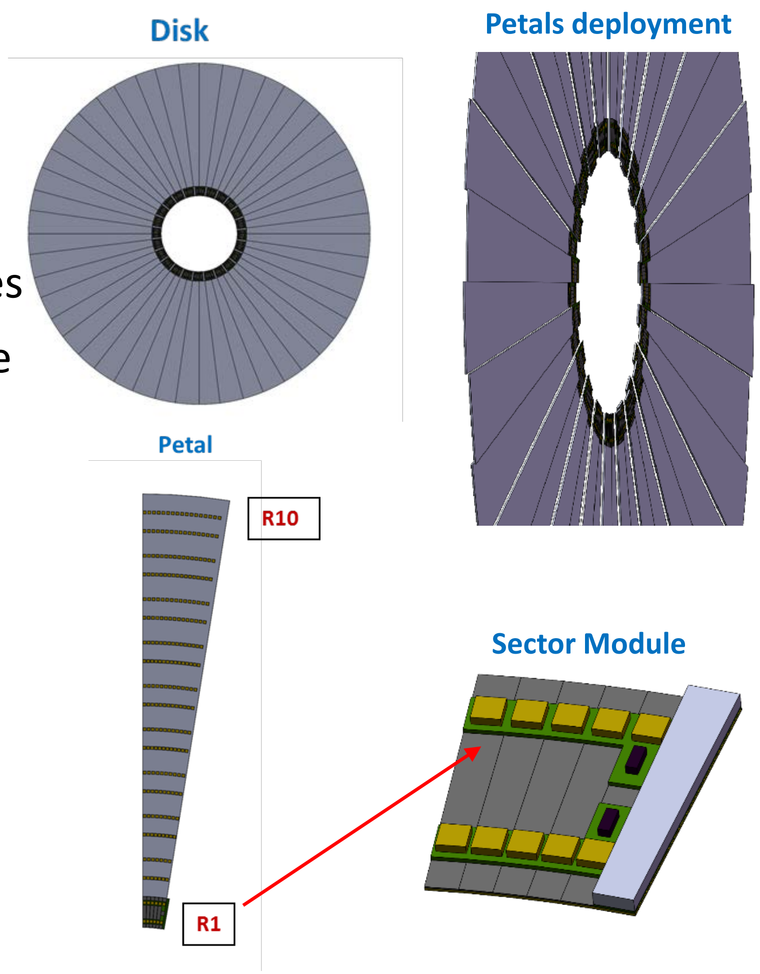
Better results but more materials. Candidate materials?

OTK-endcap

Endcap

- R: 400mm-1800mm
- One layer design： 20 m^2， 1024 modules
- Overlapped petals deployment to reduce the dead area

  - 24 petals/ layer
  - 10 rows/petal
  - 8^o per row，
  - Overlap 0.5^o/petal
  - 140 mm / row at R direction



Summary

- VTX
  - For the barrel, detailed mechanical design supported by FEA and cooling simulation, also by experiences from previous VTX prototyping.
  - For the curved MPAS, more to be studied both on the support design and cooling.
- OTK
  - Preliminary mechanical design and thermal analysis on barrel
  - a feasible cooling solution to be converged and detailed support design with cooling integrated will be followed
  - barrel and endcaps fixation on adjacent detectors?