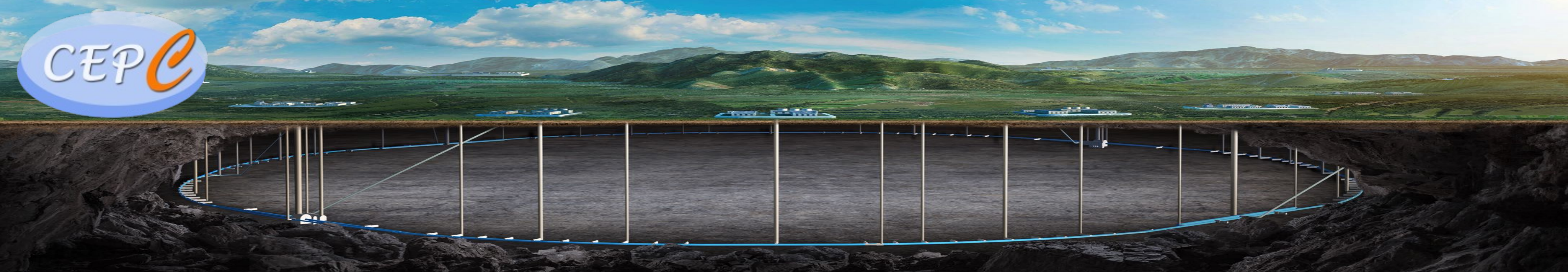


CEPC Silicon Tracker Progress Report (10)

Qi Yan

On behalf of the Silicon Tracker Group

Nov 5, 2024

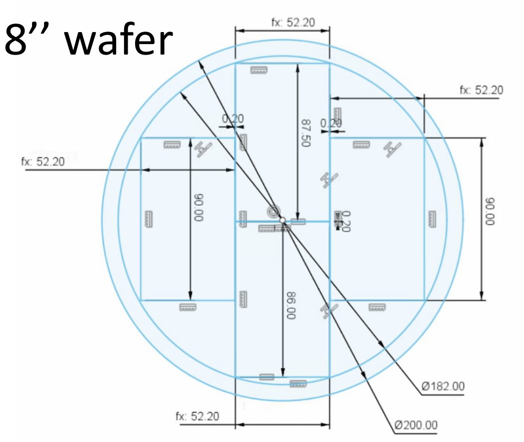
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

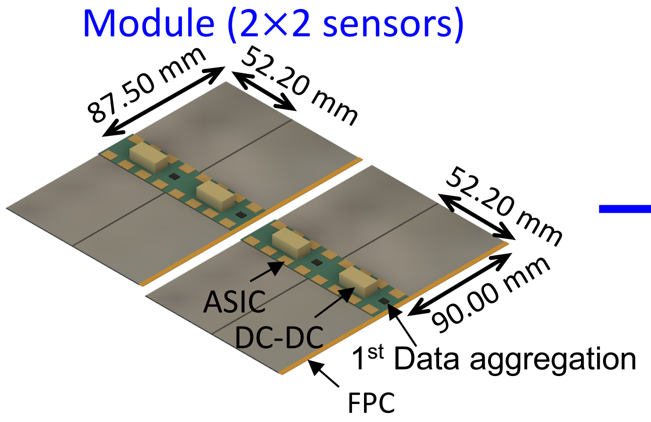
IDRC Review Comment (OTK LGAD)

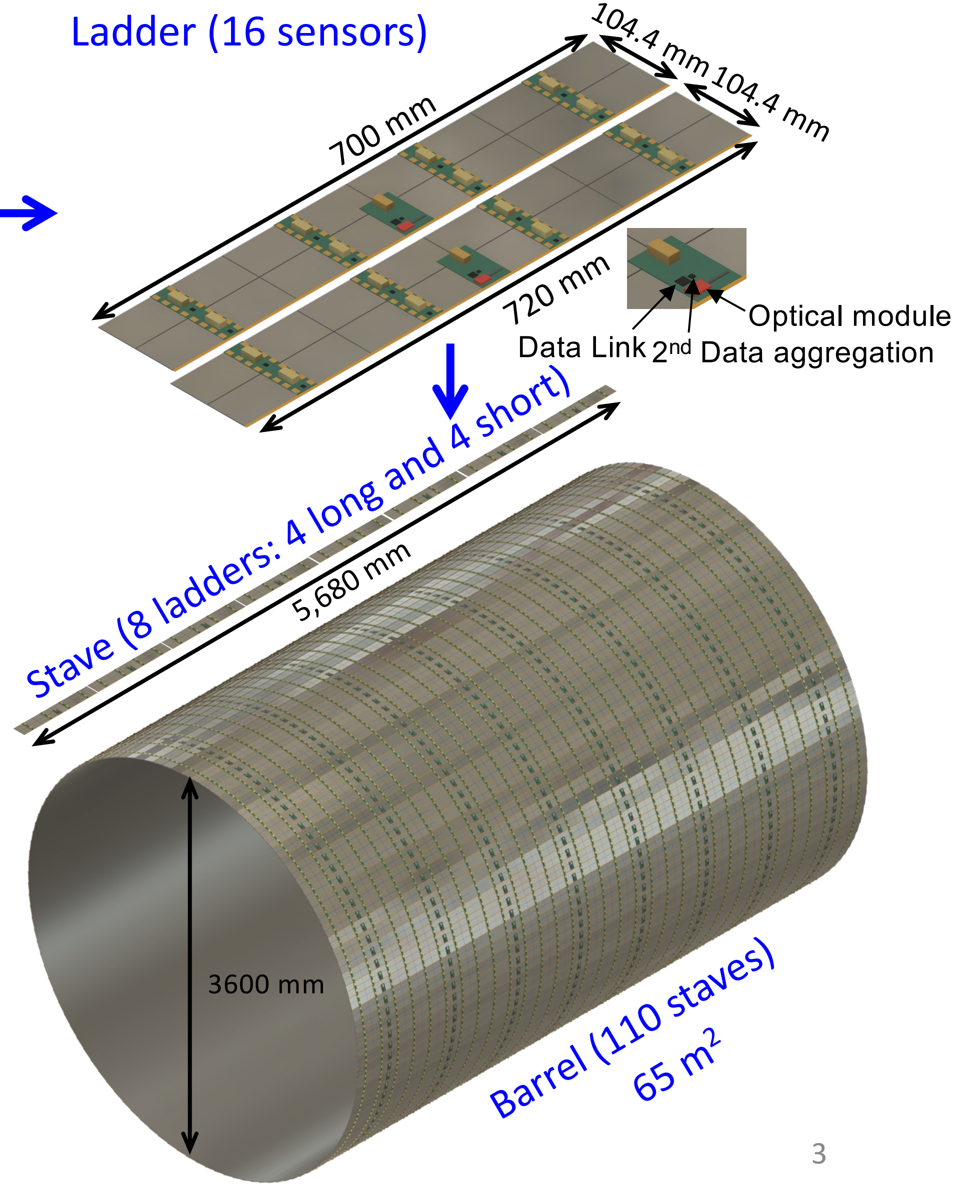
- The capacitance of some sensors will be large (up to ~10 pF) which will make the noise jitter and rise time such that it will be difficult to achieve the desired time resolution.

This is one of our main concerns. In the coming years, we plan to tape out a few phototypes to study the relationship between time resolution and capacitance as related to strip length.

OTK Barrel Design with AC-LGAD Long Strips



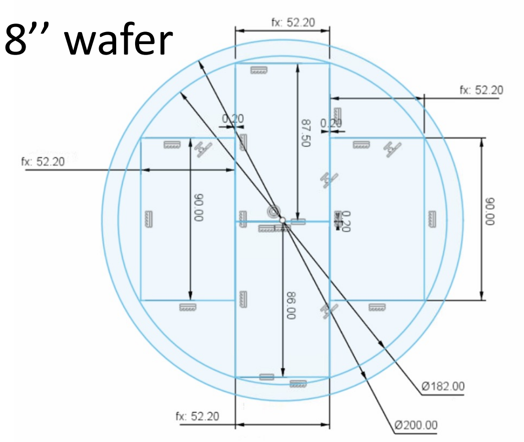


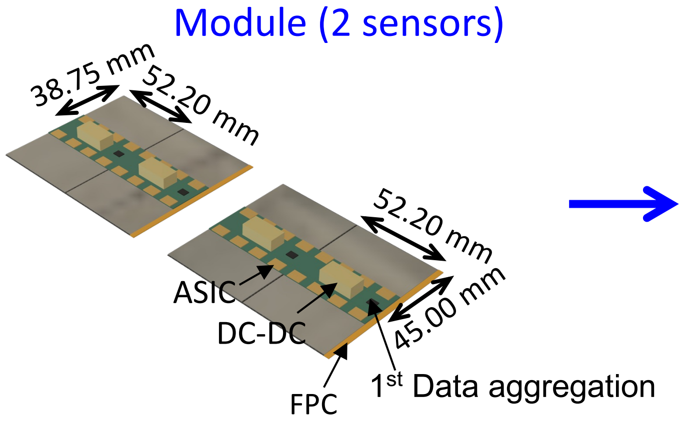


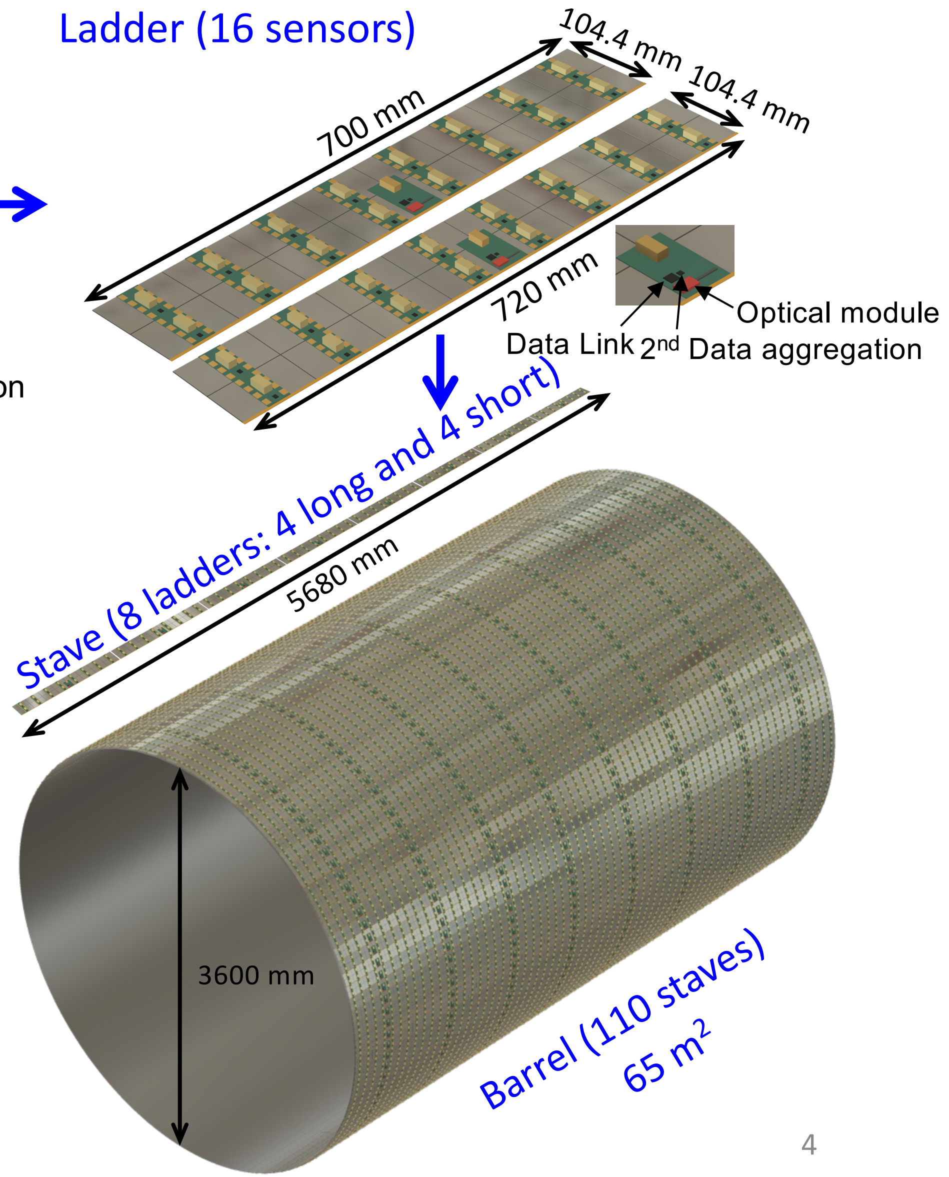
- CEPC outer silicon tracker (OTK) utilizes AC-LGAD (Low Gain Avalanche Detector) developed by IHEP-IME:
  - Sensor size: 8.75 cm × 5.22 cm
    9.00 cm × 5.22 cm
  - Strip number per sensor: 512
  - Strip pitch size: 100 μm
  - Spatial resolution: 10 μm
  - Time resolution: 50 ps
  - Power consumption: ~300 mW/cm^2

Maximum usage of silicon wafers for OTK barrel: a total 3,520 wafers, with 15% higher efficiency compared to a conventional single-piece sensor cut from a wafer.

OTK Barrel Design with AC-LGAD Short Strips



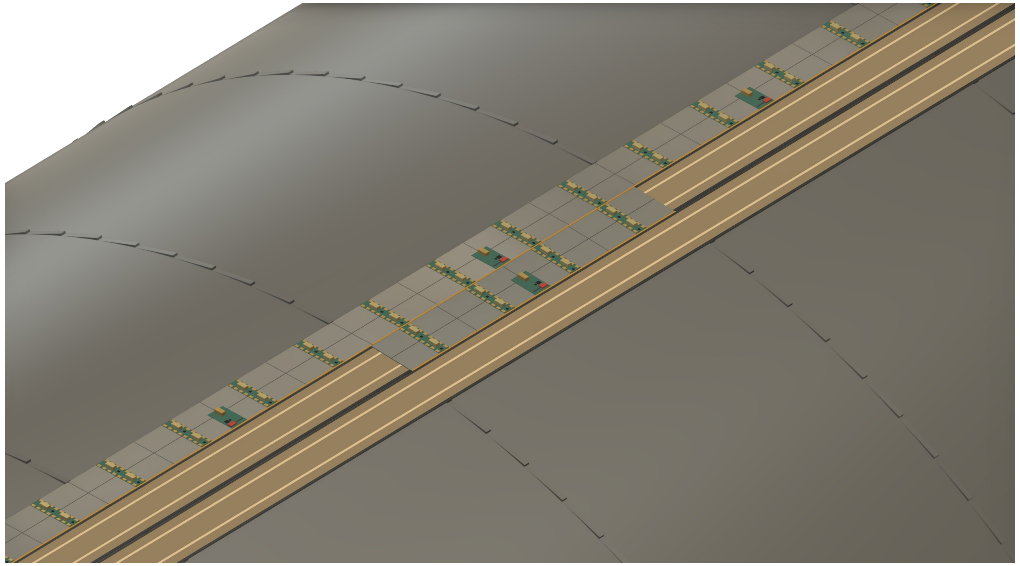


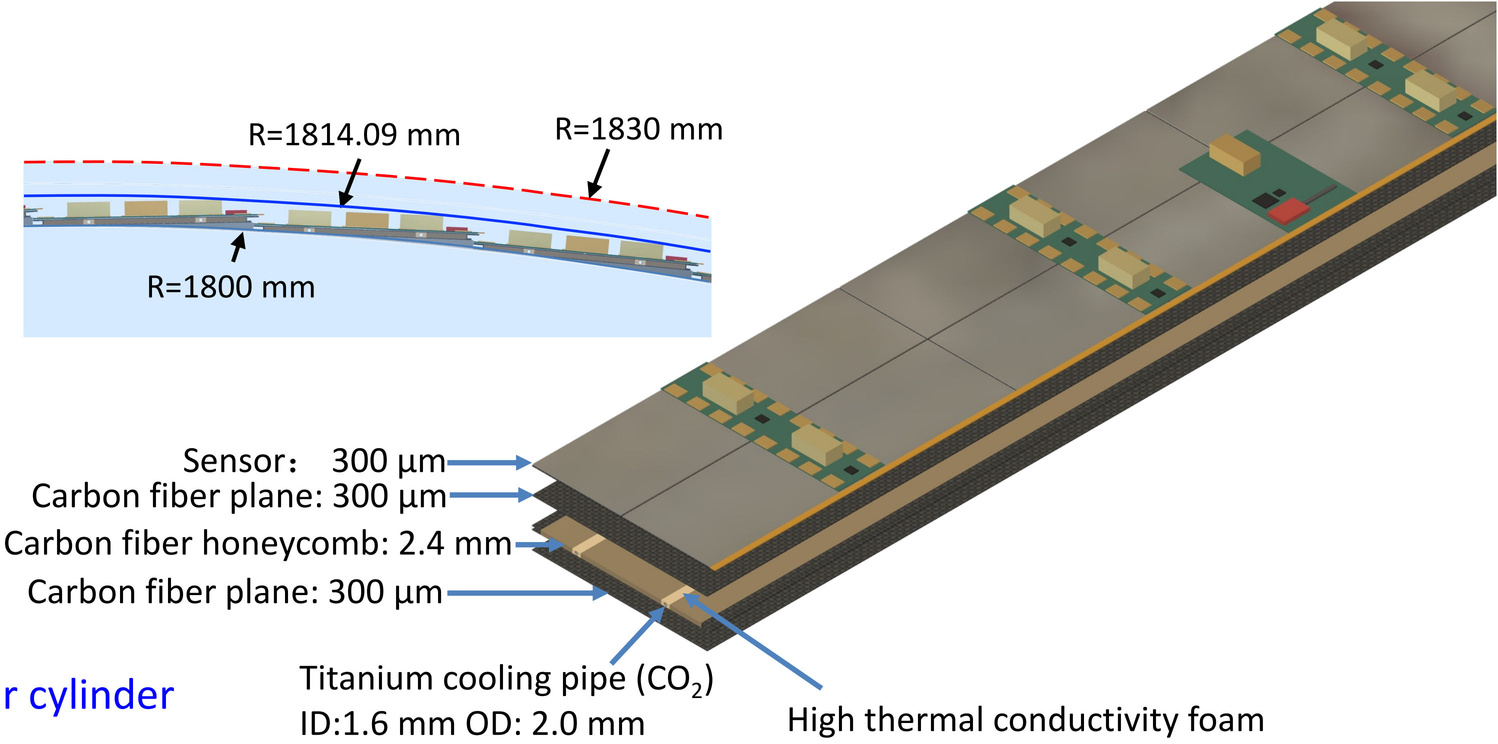


- CEPC outer silicon tracker (OTK) utilizes AC-LGAD (Low Gain Avalanche Detector) developed by IHEP-IME:
  - Sensor size: 8.75 cm × 5.22 cm (with 2 sets of strips)
    9.00 cm × 5.22 cm (with 2 sets of strips)
  - Strip number per sensor: 512
  - Strip pitch size: 100 μm
  - Spatial resolution: 10 μm
  - Time resolution: 50 ps
  - Power consumption: ~300 mW/cm^2

Maximum usage of silicon wafers for OTK barrel: a total 3,520 wafers, with 15% higher efficiency compared to a conventional single-piece sensor cut from a wafer.

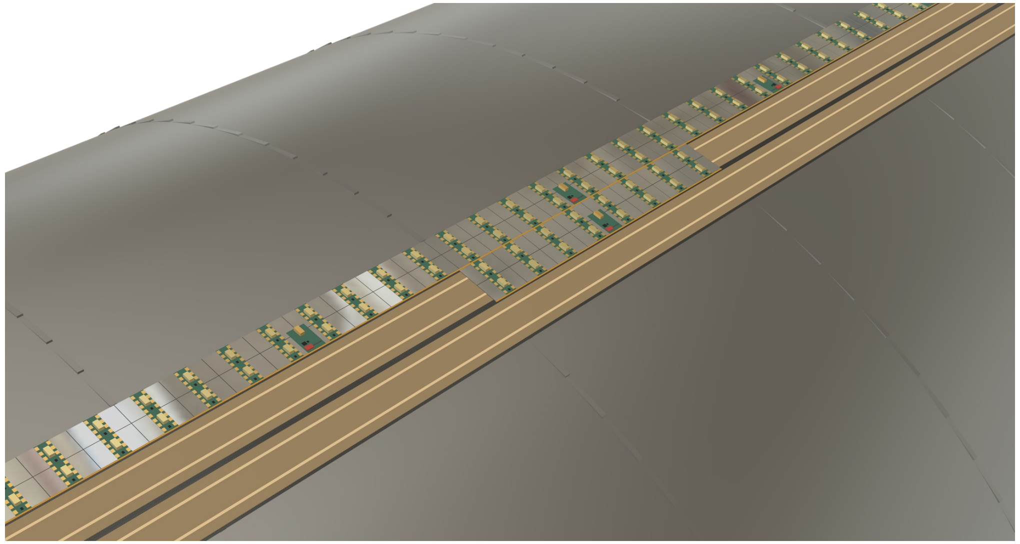
OTK Barrel Mechanical and Cooling with Long Strips

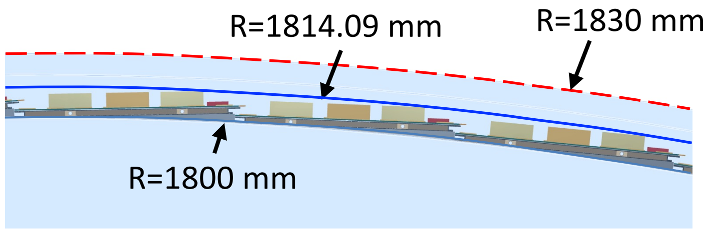


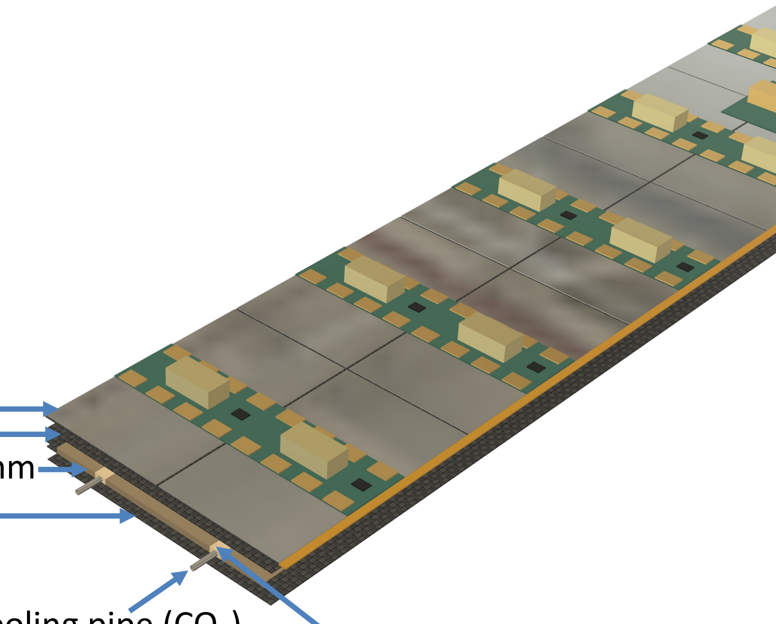


- The outer barrel of the TPC is made of a carbon fiber cylinder with stepped ramp rings used for OTK support.
- The installation of OTK stave begins with the carbon fiber honeycomb and cooling pipe (~6 m in length), along with the lower support carbon fiber plane.
- Afterwards, the OTK ladders are inserted one by one. Each ladder (~0.7 m) has its own support, consisting of 16 sensors, electronic components, and a carbon fiber plane.

OTK Barrel Mechanical and Cooling with Short Strips





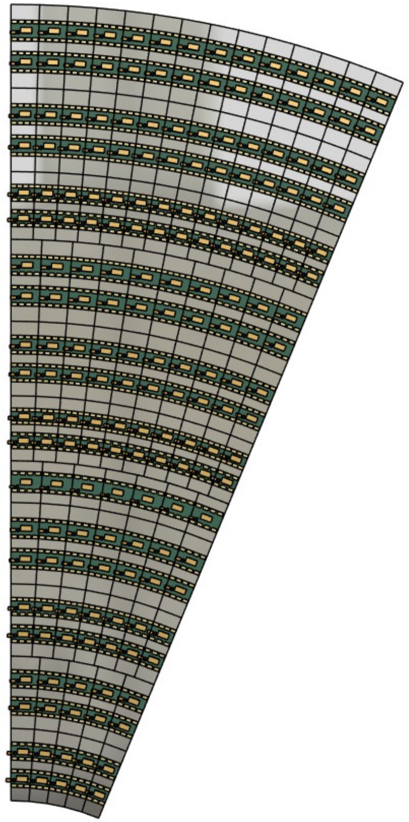


- The outer barrel of the TPC is made of a carbon fiber cylinder with stepped ramp rings used for OTK support.
- The installation of OTK stave begins with the carbon fiber honeycomb and cooling pipe (~6 m in length), along with the lower support carbon fiber plane.
- Afterwards, the OTK ladders are inserted one by one. Each ladder (~0.7 m) has its own support, consisting of 16 sensors, electronic components, and a carbon fiber plane.

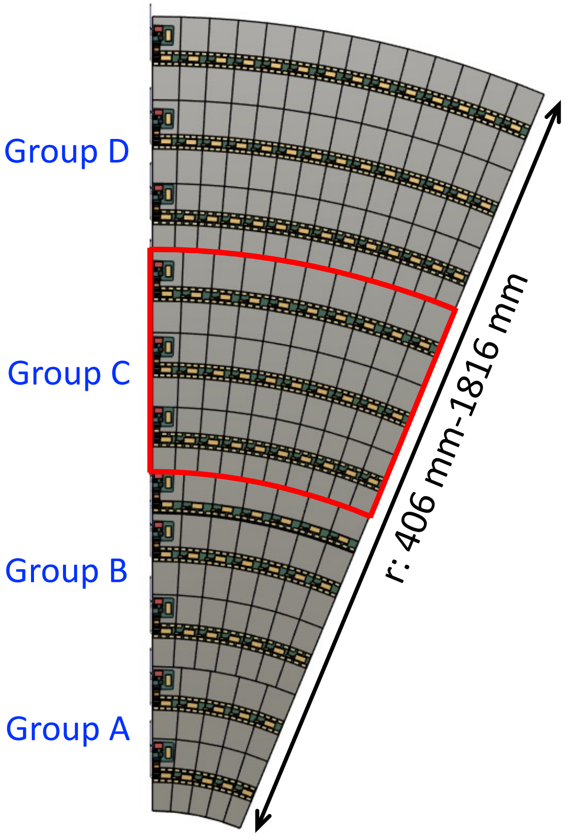
- More electronic components and readout channels are introduced for the short strip sensor (~4 cm).

CEPC OTK Endcap Electronic Components

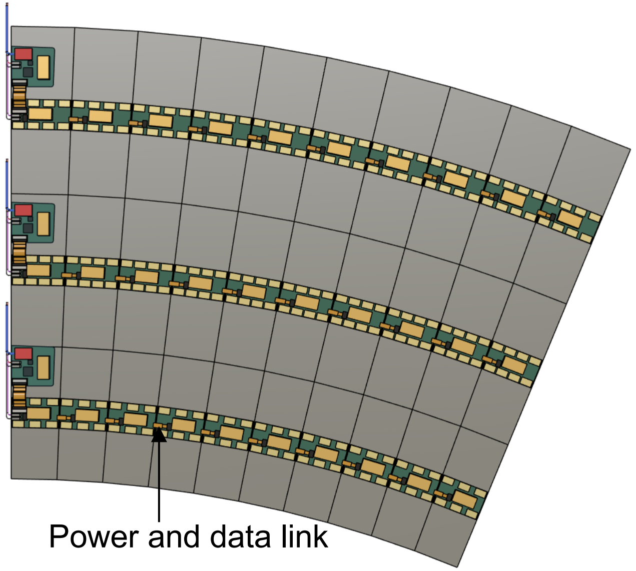
1/16 Sector:



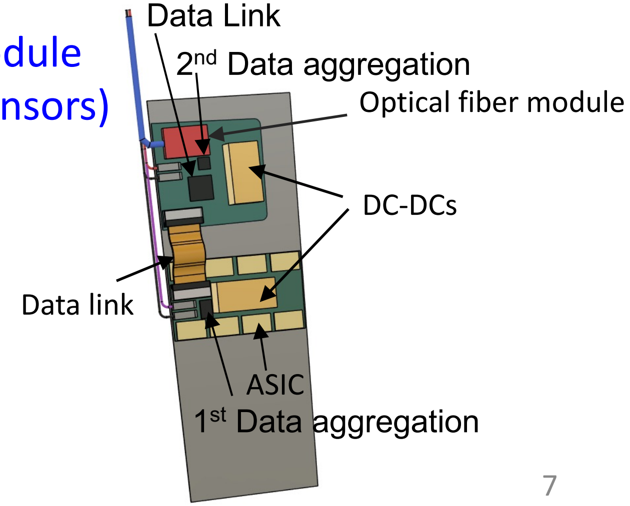
1/16 Sector:



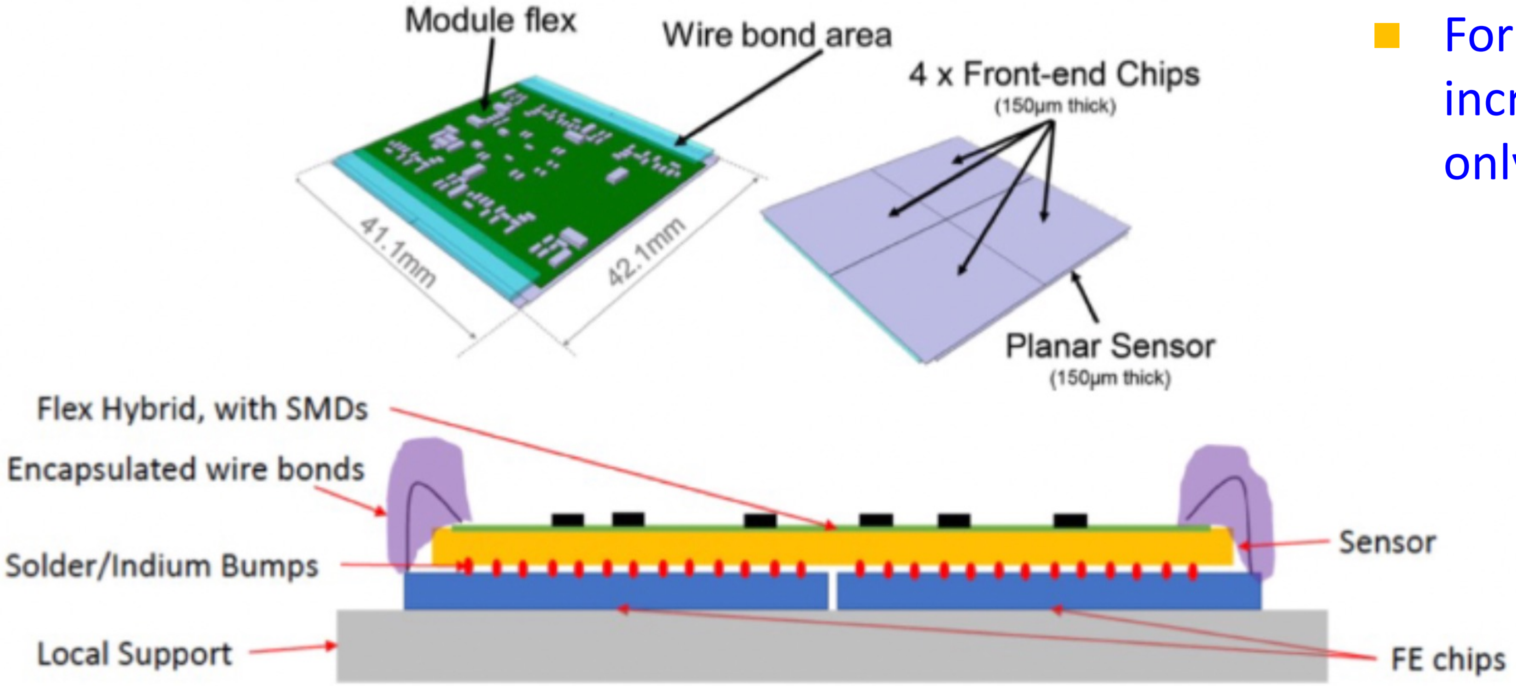
Group C sensors:



Module (2 sensors)

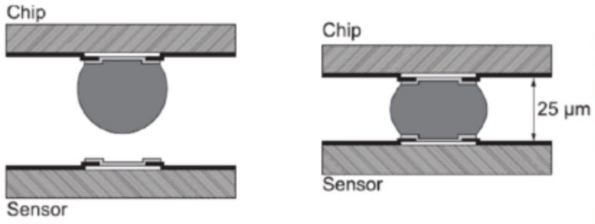


OTK Assembly for Sensor Dimension <2 cm

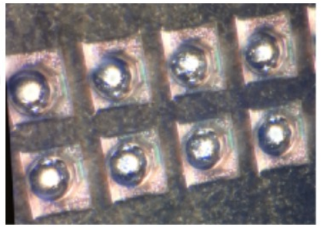


- For OTK sensor with dimension of ~2 cm and increased electronics component coverage, only flip chip with bump bonding is feasible.

Bump bonding
Technique : Solder and Indium



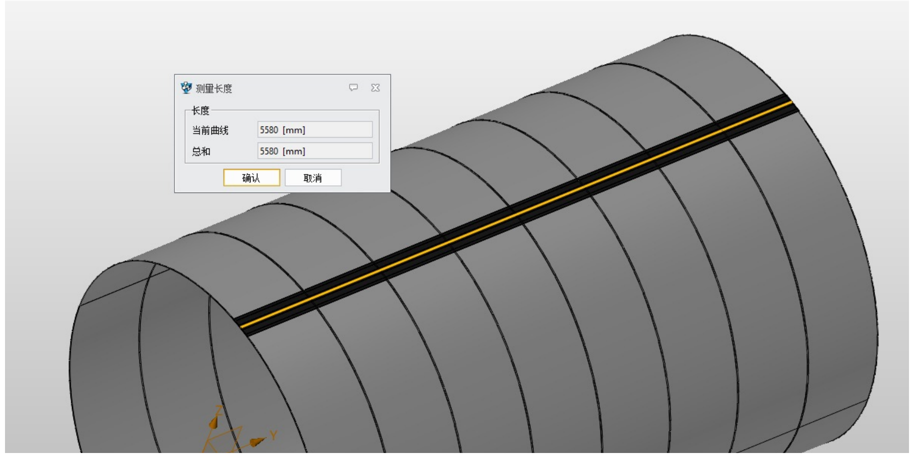
~640k pixels in quads



Discussed with Xiongbo YAN *and* Jingbo YE.

For sensors <2 cm, assembly is even more difficult. Mei ZHAO is conducting simulation to understand the correlation between capacitance (and related performance) and sensor size.

Study of OTK Ladder Deformation

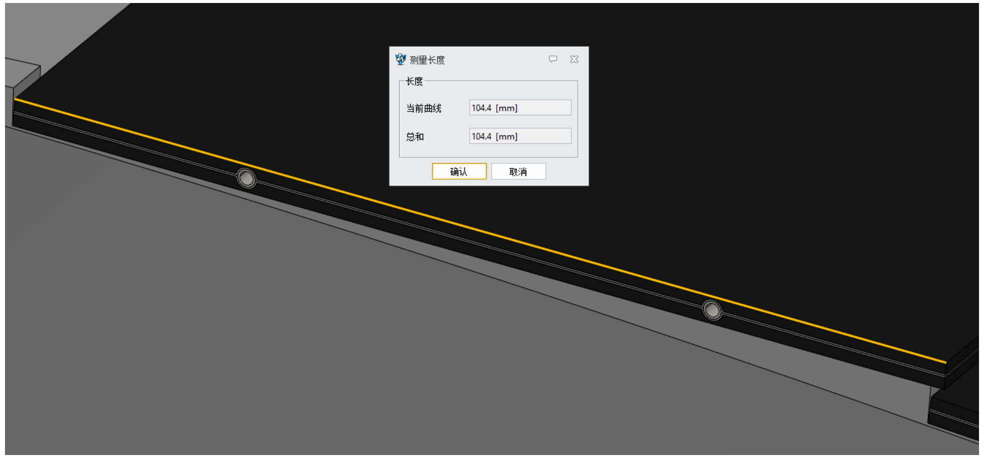


测量长度

长度

当前曲线 5580 [mm]

总和 5580 [mm]

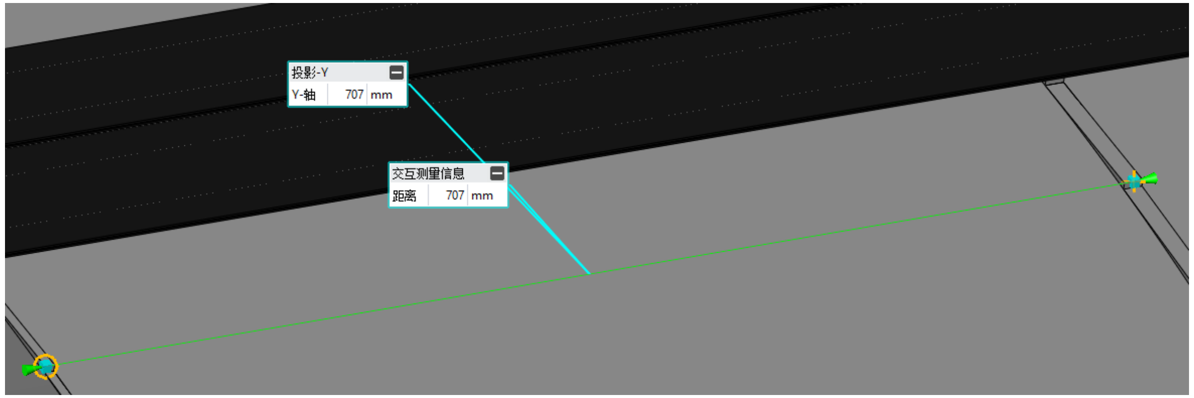


测量长度

长度

当前曲线 104.4 [mm]

总和 104.4 [mm]

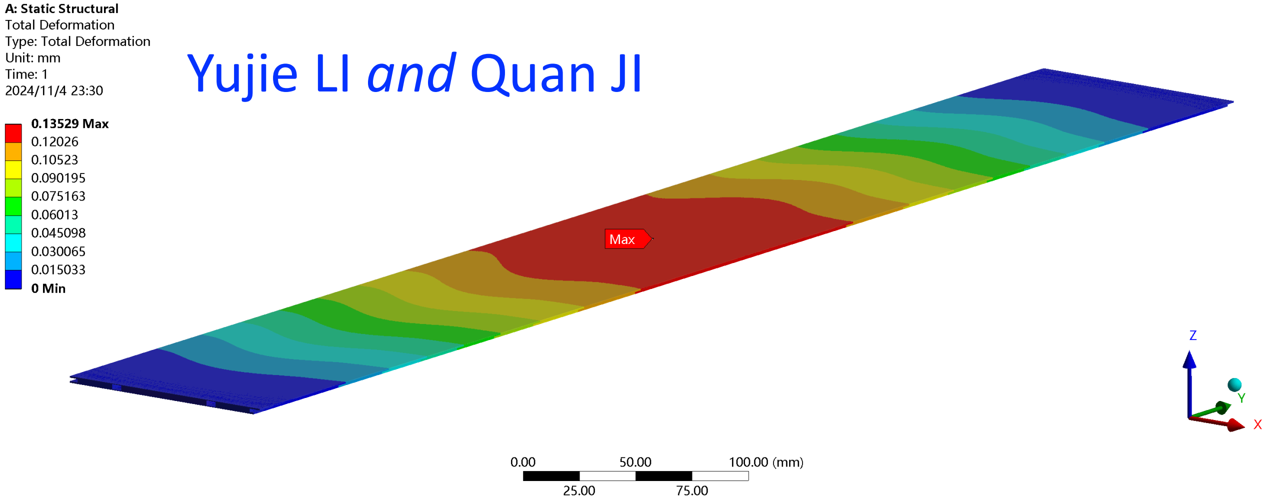


投影-Y

Y-轴 707 mm

交互测量信息

距离 707 mm



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
2024/11/4 23:30

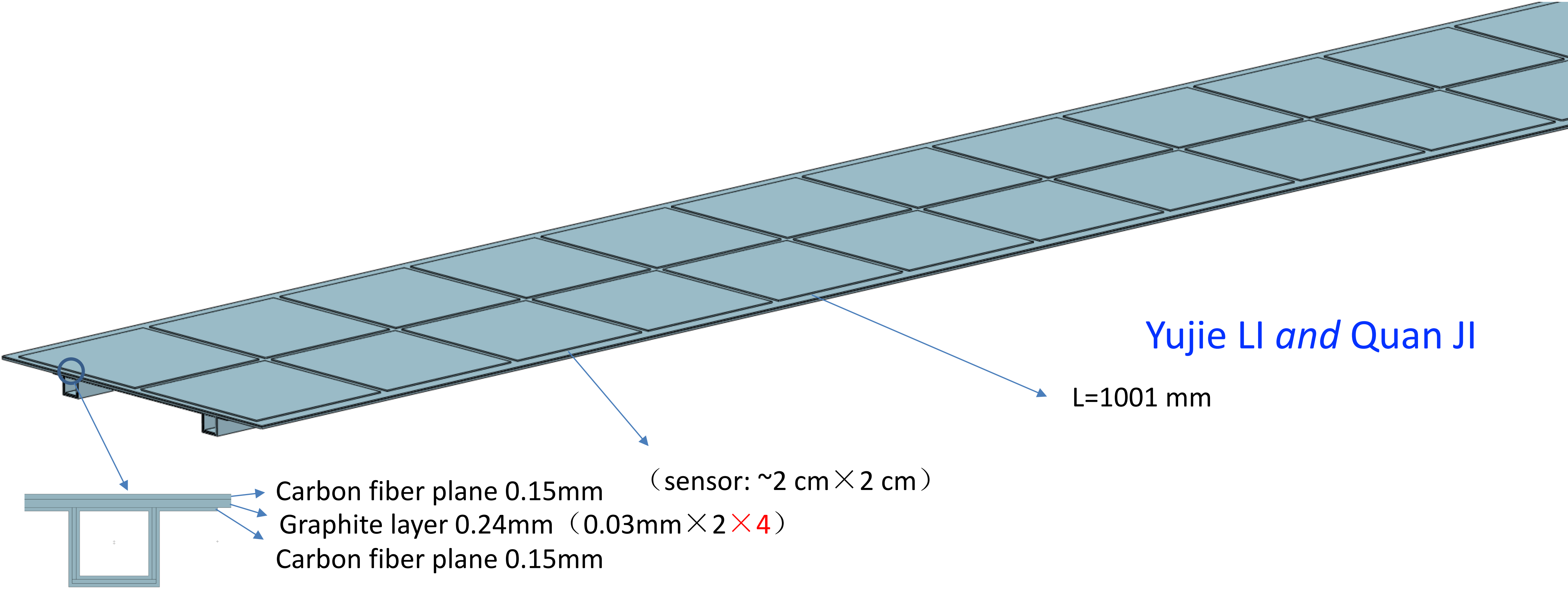
0.13529 Max
0.12026
0.10523
0.090195
0.075163
0.06013
0.045098
0.030065
0.015033
0 Min

Yujie LI *and* Quan JI

Under its own weight, including its electronics components, the maximum deformation of a single ladder (720 mm) is calculated to be ~0.135 mm.

Simulation of ITK Thermal Performance

To make the model more realistic, the sensor structure and essential thermal components have been taken into account.



L=1001 mm

（sensor: ~2 cm×2 cm）

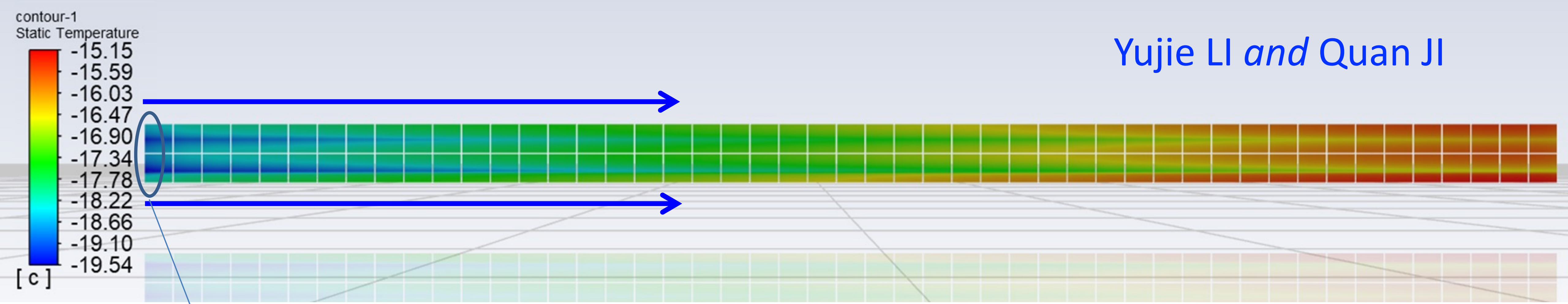
Carbon fiber plane 0.15mm

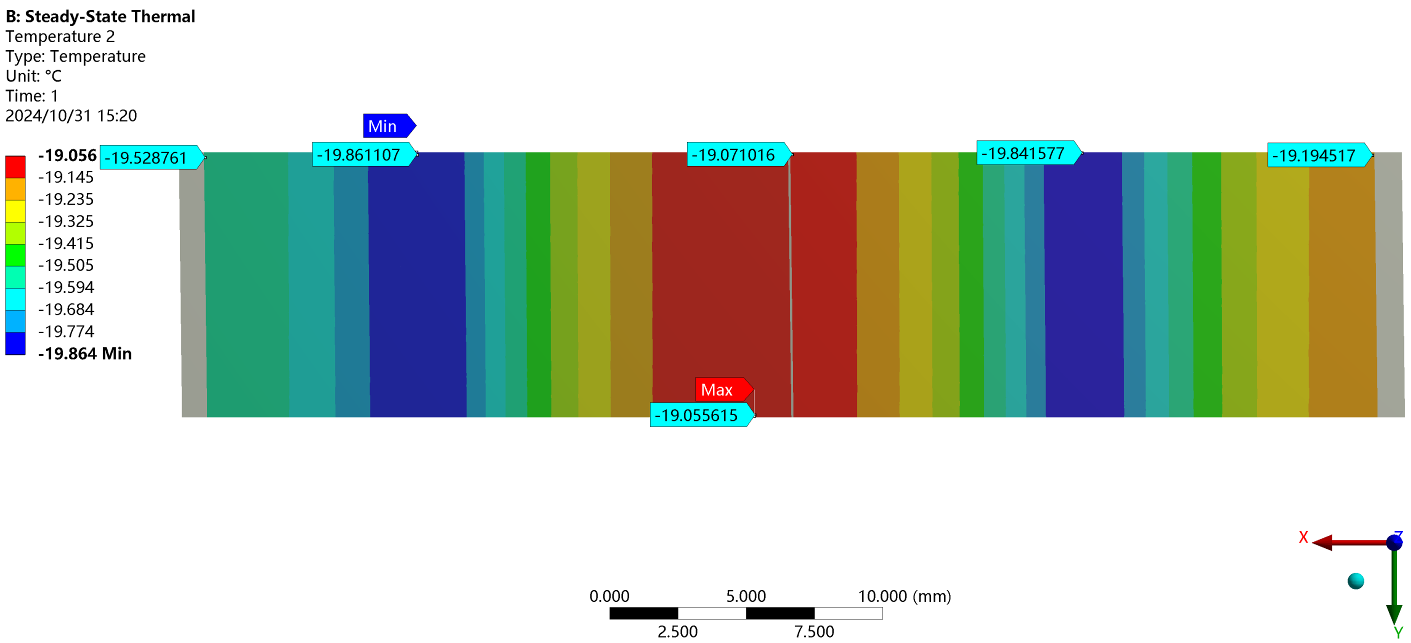
Graphite layer 0.24mm（0.03mm×2×4）

Carbon fiber plane 0.15mm

Yujie LI *and* Quan JI

Yujie LI *and* Quan JI

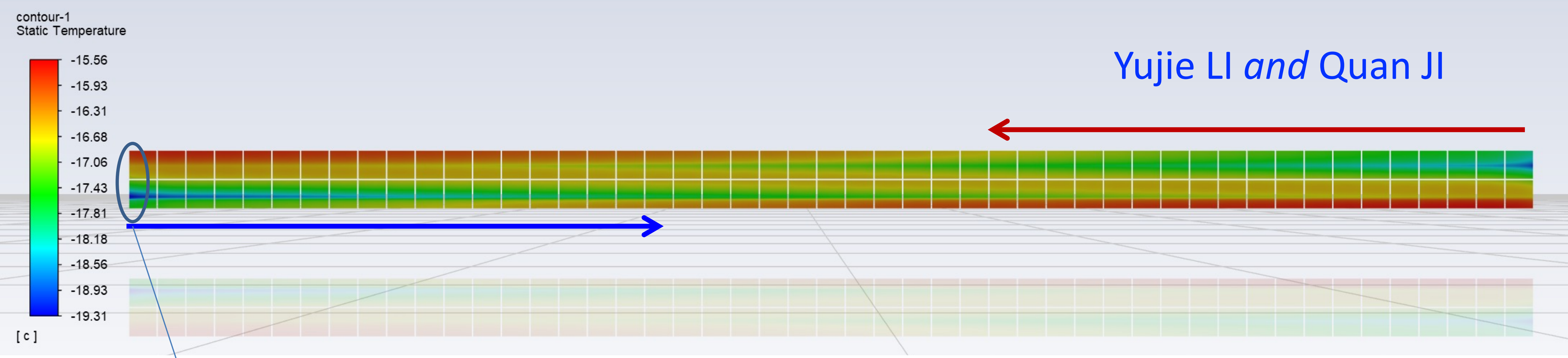




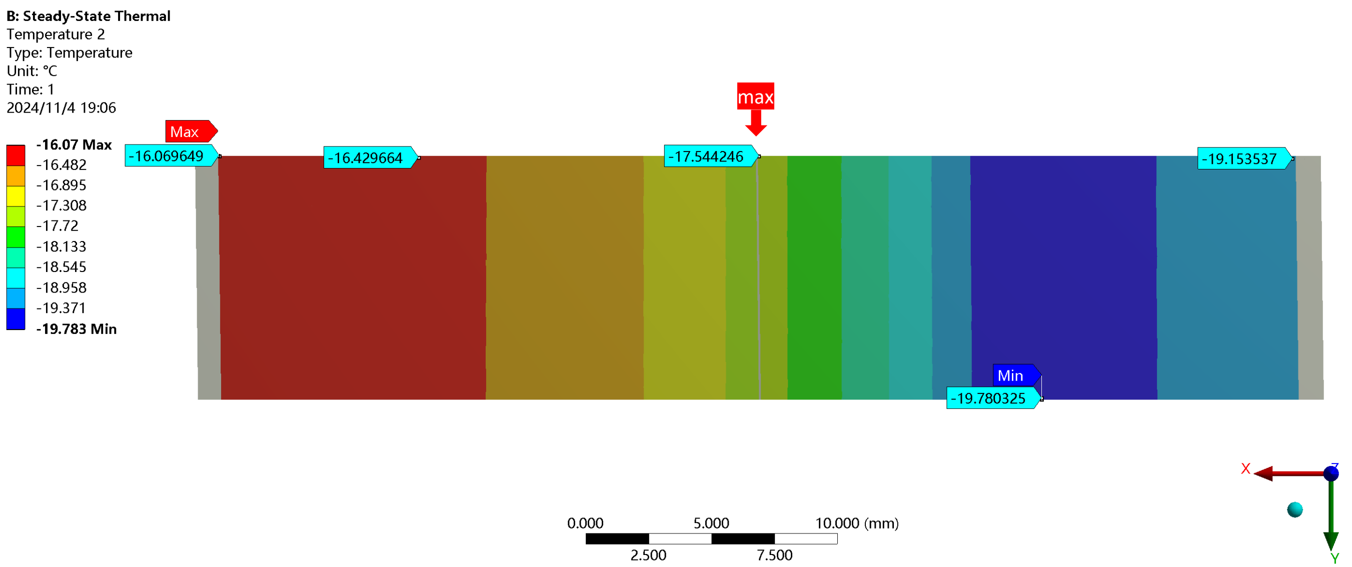
Using liquid CO_2 at -20°C with an inlet flow rate of 0.003 kg/s from one side:

The maximum longitudinal temperature difference on the stave: 4.39 °C

The maximum temperature difference on a single sensor: ~0.8°C



Yujie LI *and* Quan JI



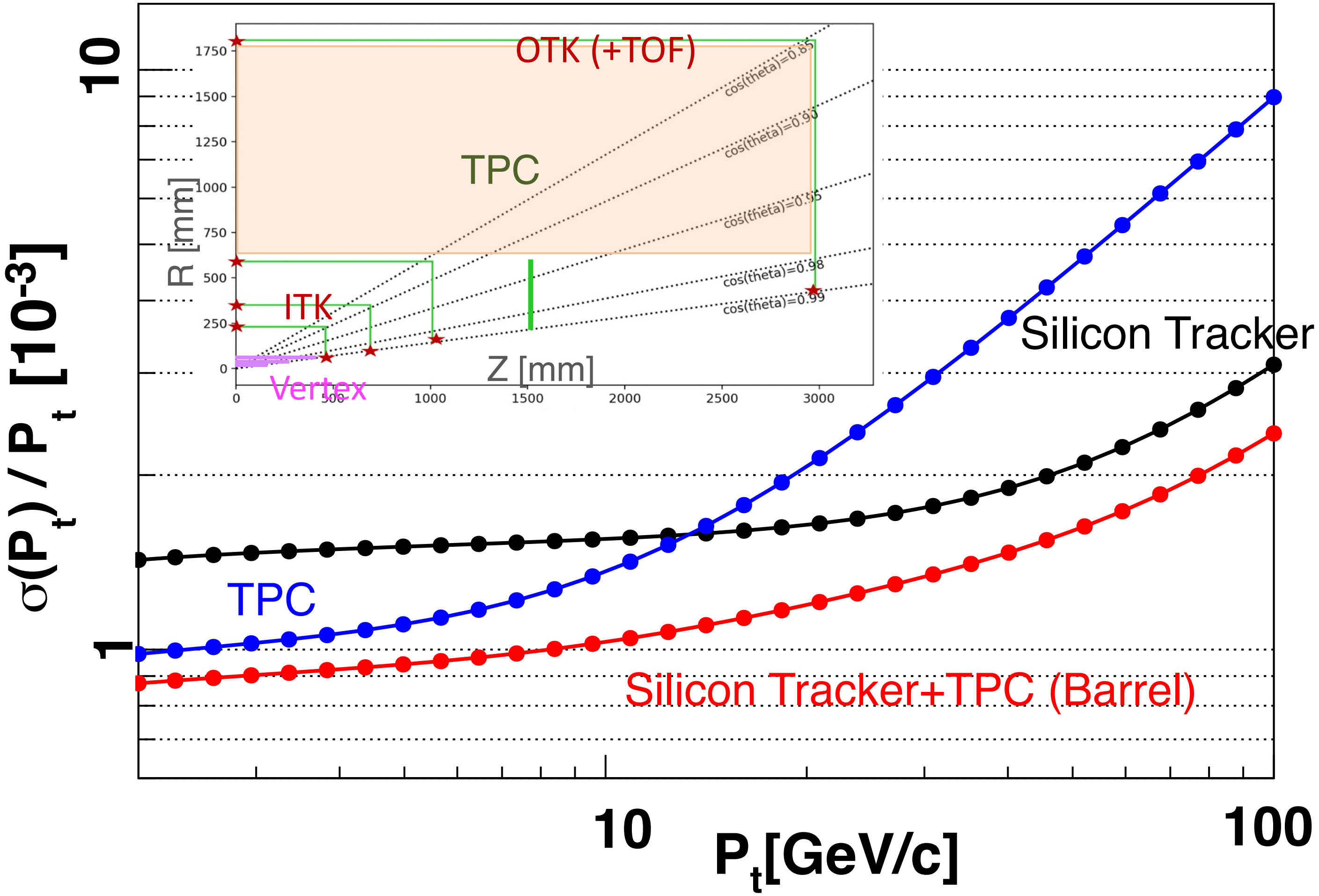
Using liquid CO_2 at -20°C with an inlet flow rate of 0.003 kg/s from both sides:

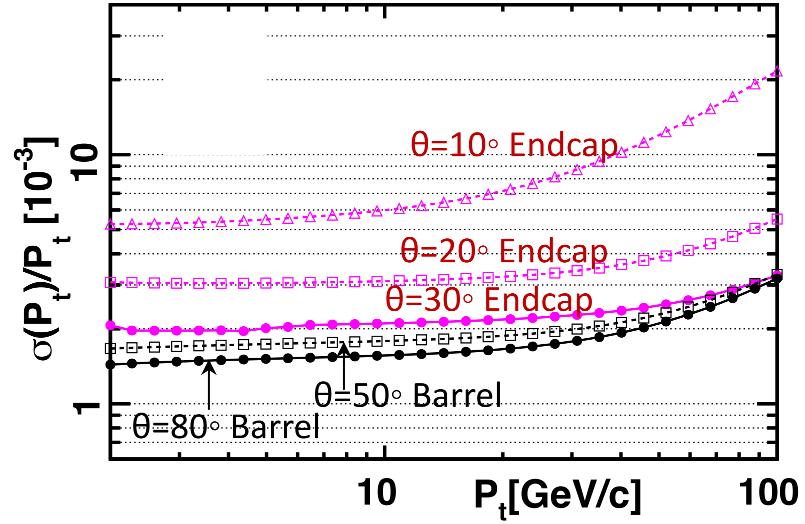
The maximum longitudinal temperature difference on the stave: 3.75°C

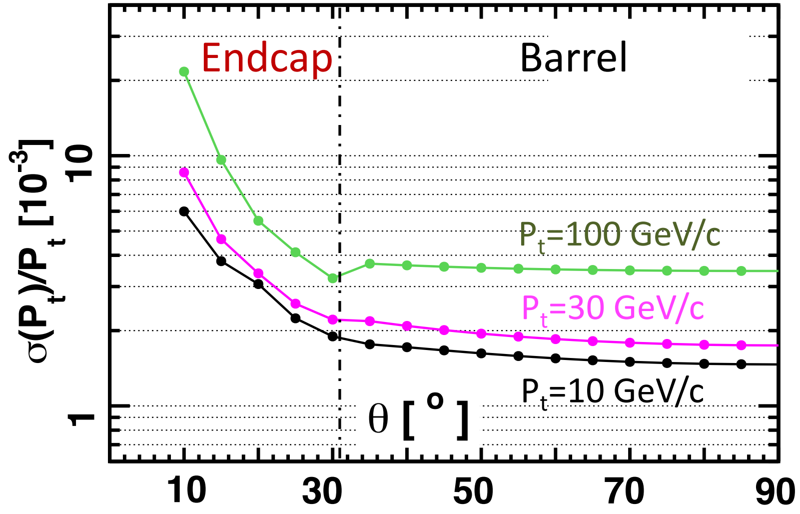
The maximum temperature difference on a single sensor: ~2.24 °C

The maximum temperature difference decreased compared to single-side inlet (4.39°C → 3.75°C), but the temperature gradient on a single sensor increased significantly (0.8°C → 2.24°C).

CEPC Tracker Performance from Simulation: Momentum Resolution



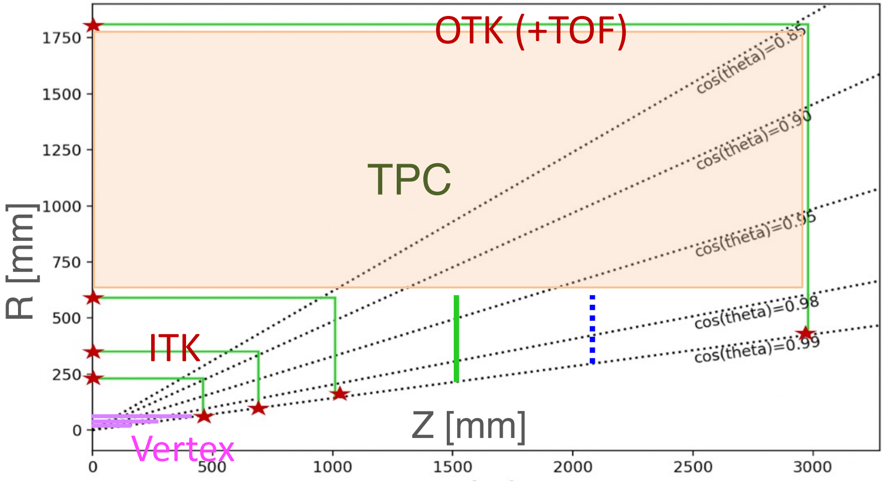


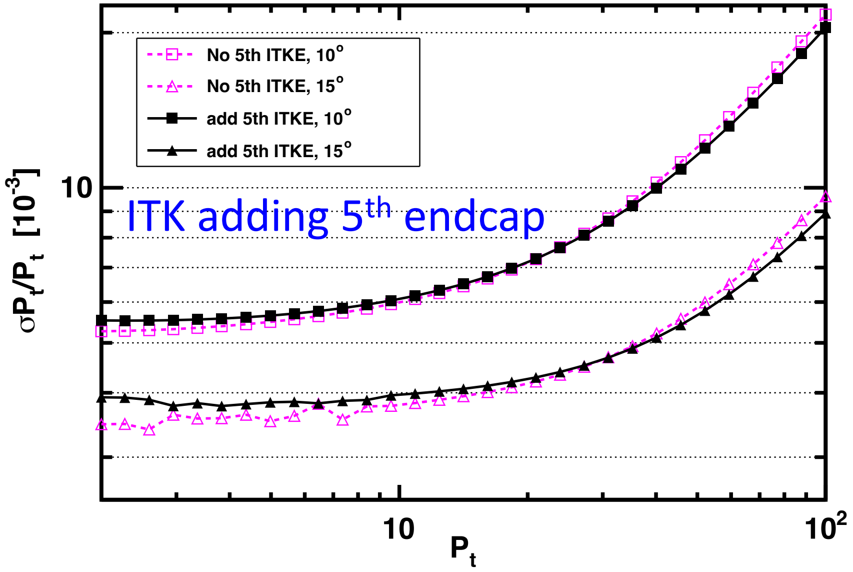


Silicon Tracker momentum resolution angular dependence

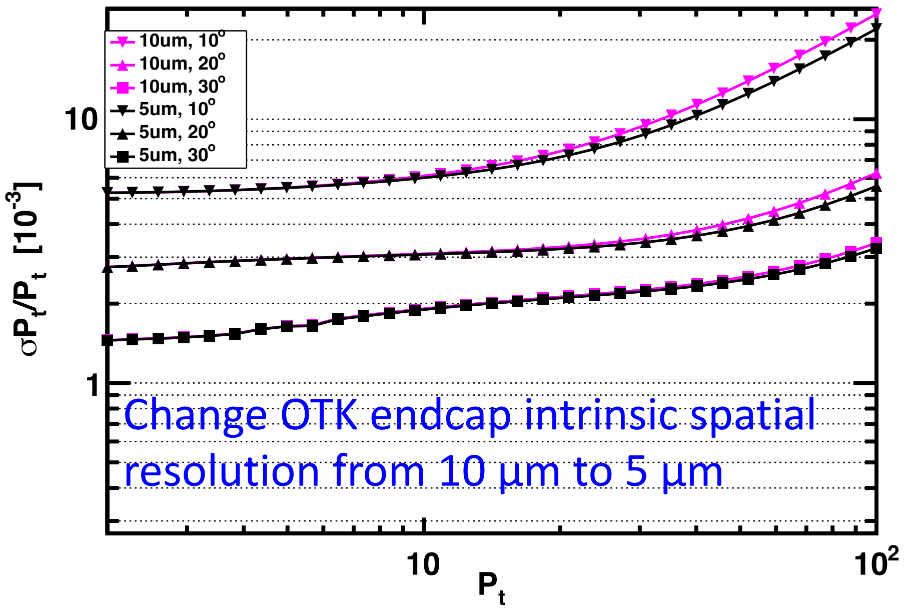
The momentum resolution at endcap degrades due to the shorter lever arm (r) as: $\sigma(P_t)/P_t \propto 1/r^2$. Is any way to improve?

Sensitivity of Endcap Momentum Resolution





ITK adding 5th endcap

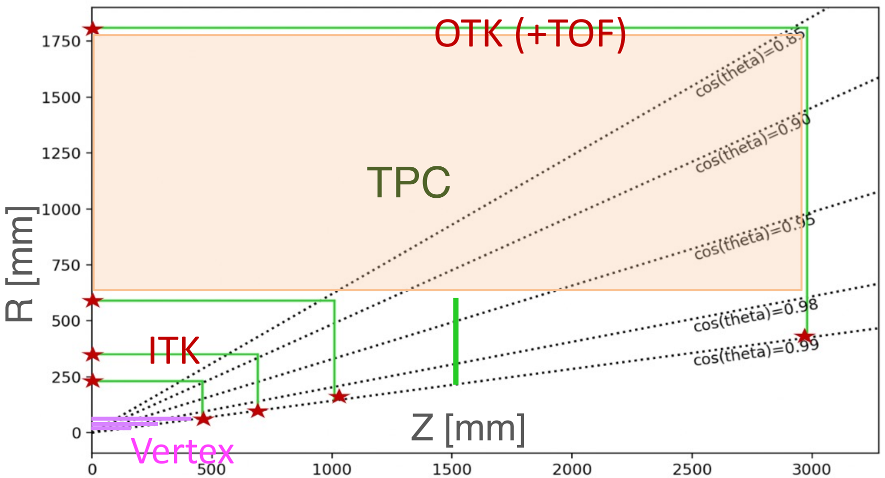


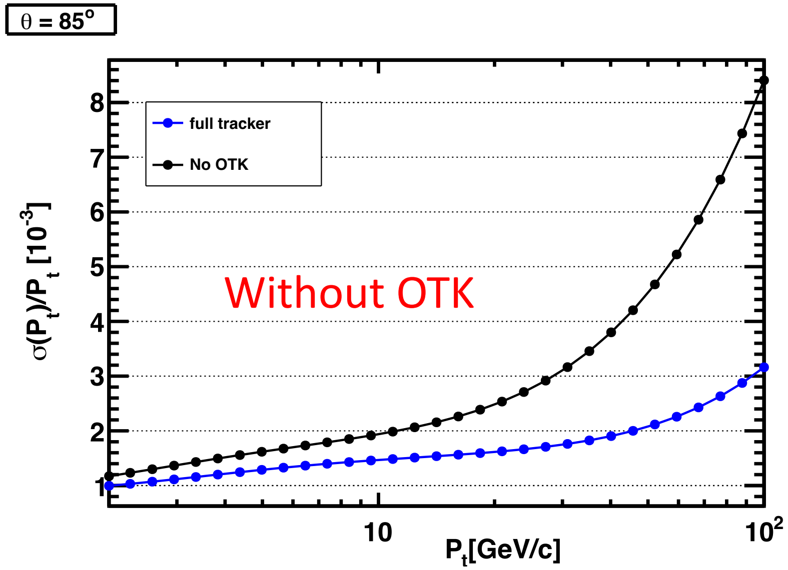
Change OTK endcap intrinsic spatial resolution from 10 μm to 5 μm

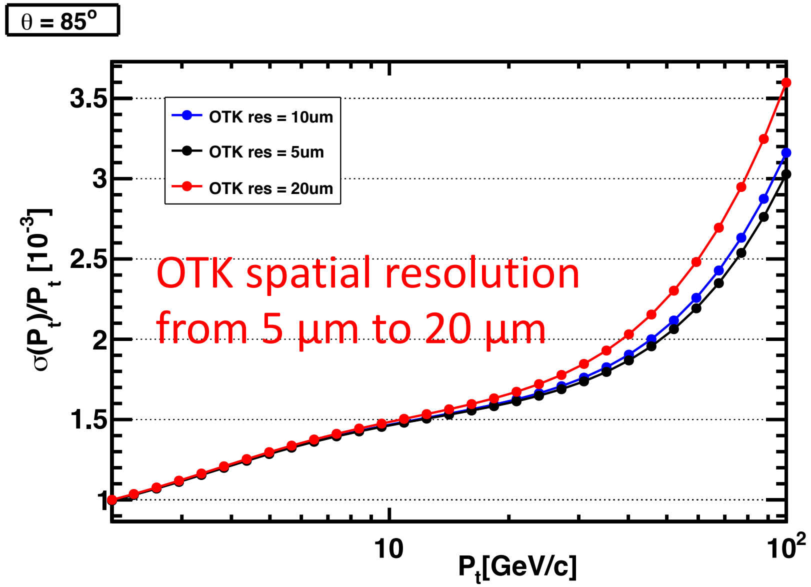
Improving intrinsic resolution is not beneficial.

Compared to the intrinsic spatial resolution, multiple scattering dominates momentum resolution below 50 GeV/c.

Sensitivity of Barrel Momentum Resolution





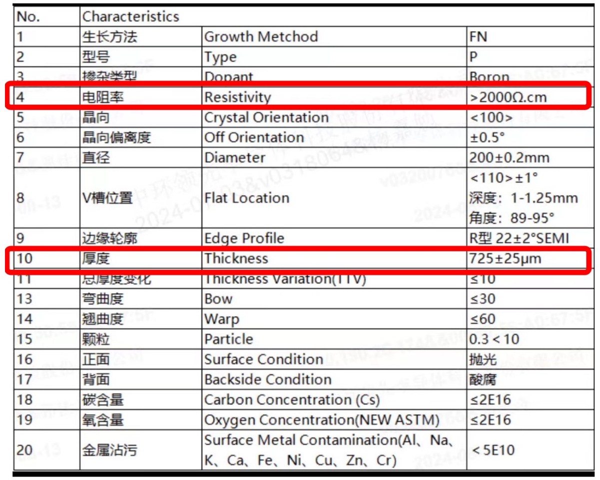


An OTK spatial resolution of ~10 μm is crucial for the overall track momentum resolution.

CMOS Strip Chip Project Introduction and Review

硅片厂商:

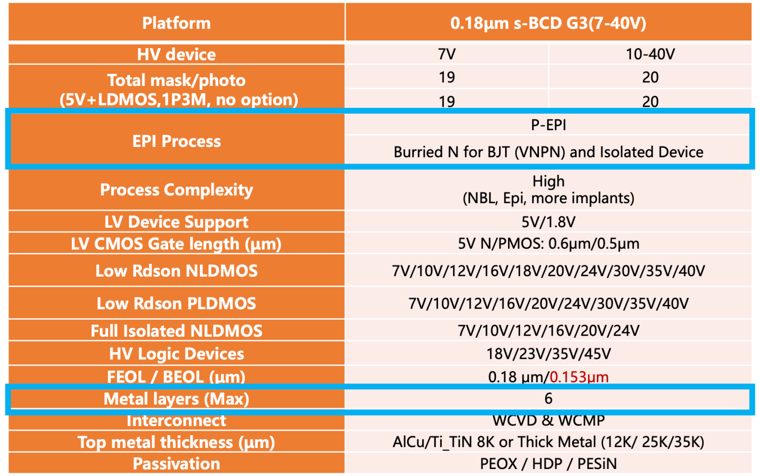
1. **天津中环**： 2K高阻片/8-inch
2. *进口晶圆：4K高阻片/8-inch*
3. 上华：正常阻抗片/8-inch



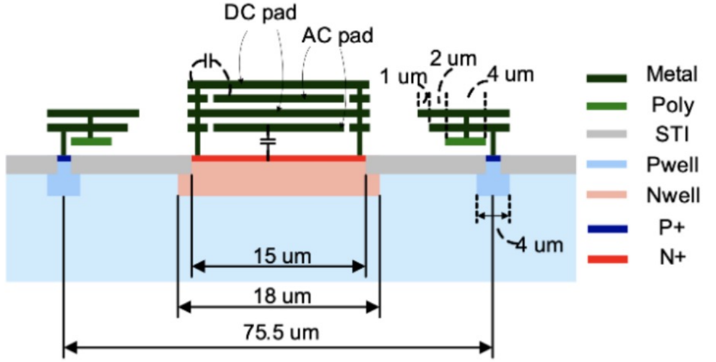
No.	Characteristics		
1	生长方法	Growth Metchod	FN
2	型号	Type	P
3	掺杂类型	Dopant	Boron
4	电阻率	Resistivity	>2000Ω.cm
5	晶向	Crystal Orientation	<100>
6	晶向偏离度	Off Orientation	±0.5°
7	直径	Diameter	200±0.2mm
8	V槽位置	Flat Location	<110>±1° 深度：1-1.25mm 角度：89-95°
9	边缘轮廓	Edge Profile	R型 22±2°SEMI
10	厚度	Thickness	725±25μm
11	总厚度变化	Thickness Variation(TTV)	≤10
13	弯曲度	Bow	≤30
14	翘曲度	Warp	≤60
15	颗粒	Particle	0.3＜10
16	正面	Surface Condition	抛光
17	背面	Backside Condition	酸腐
18	碳含量	Carbon Concentration (Cs)	≤2E16
19	氧含量	Oxygen Concentration(NEW ASTM)	≤2E16
20	金属沾污	Surface Metal Contamination(Al、Na、K、Ca、Fe、Ni、Cu、Zn、Cr)	＜5E10

天津中环硅片

无锡上华0.18um BCD工艺



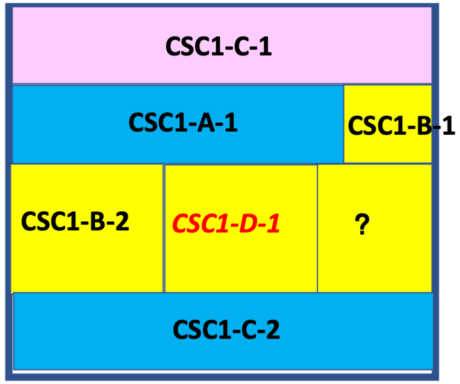
Platform	0.18μm s-BCD G3(7-40V)	
HV device	7V	10-40V
Total mask/photo (5V+LDMOS,1P3M, no option)	19	20
	19	20
EPI Process	P-EPI	
	Burried N for BJT (VNPN) and Isolated Device	
Process Complexity	High (NBL, Epi, more implants)	
LV Device Support	5V/1.8V	
LV CMOS Gate length (μm)	5V N/PMOS: 0.6μm/0.5μm	
Low Rdson NLDMOS	7V/10V/12V/16V/18V/20V/24V/30V/35V/40V	
Low Rdson PLDMOS	7V/10V/12V/16V/20V/24V/30V/35V/40V	
Full Isolated NLDMOS	7V/10V/12V/16V/20V/24V	
HV Logic Devices	18V/23V/35V/45V	
FEOL / BEOL (μm)	0.18 μm/0.153μm	
Metal layers (Max)	6	
Interconnect	WCVD & WCMP	
Top metal thickness (μm)	AlCu/Ti_TiN 8K or Thick Metal (12K/ 25K/35K)	
Passivation	PEOX / HDP / PESiN	

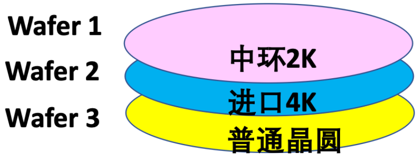


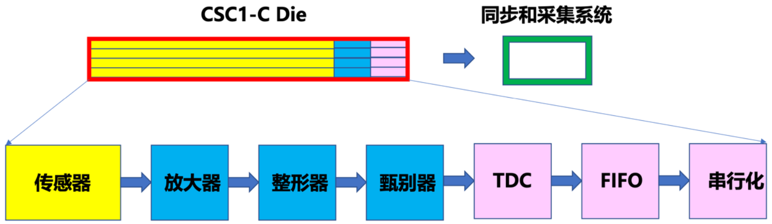
CSC1的实施方案- RETICAL设计

同样掩膜版可以用于加工不同种wafer

CSC1项目光罩排版

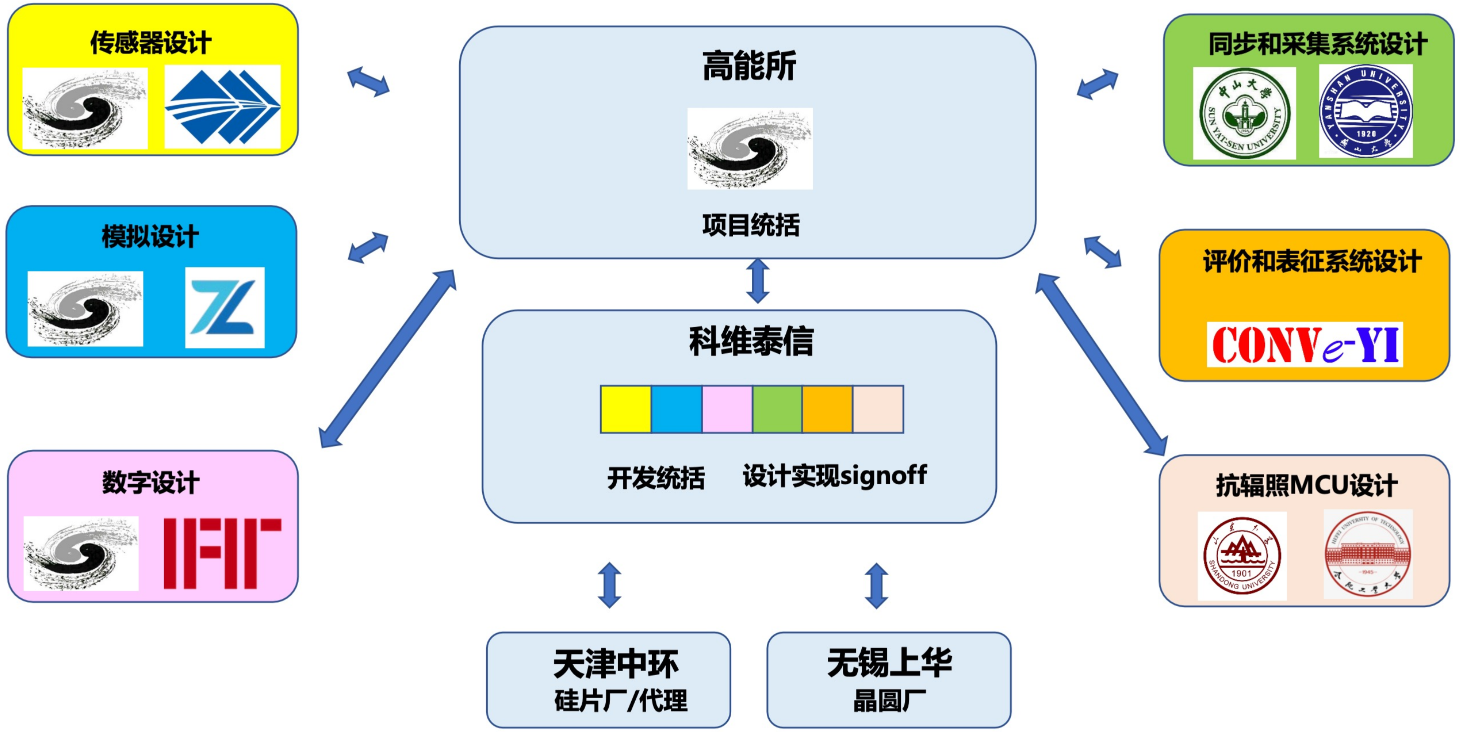






The CMOS Strip Chip project (CSC) explores a different approach for developing of fully depleted monolithic CMOS detectors. It utilizes domestic high-resistivity wafers (Tianjin Zhonghuan 2K) and CMOS foundry (CSMC, Wuxi Shanghua). The project combines efforts from both research institutes and industry (9 units currently participating).

Last Friday (November 1), we conducted the first review of CMOS strip project , inviting institute’s electronics group. The review was constructive and included a detailed discussion of the technical approach, development specifics, and project organization. Participants in the review included: 郭超英， 王铮， 魏微，叶竞波， 严雄波， 赵梅， 陆卫国， 张颖， 李刚， 李一鸣, …



CONVe-YI
北京科维泰信科技有限公司

山东高等技术研究院
SHANDONG INSTITUTE
OF ADVANCED TECHNOLOGY

中国科学院微电子研究所
INSTITUTE OF MICROELECTRONICS OF THE CHINESE ACADEMY OF SCIENCES

张江实验室
ZHANGJIANG LABORATORY

Key Discussions in the Review

The review discussed many key technical issues and was very beneficial (~4 hours discussion). The team has recorded them thoroughly:

对于20 um间距的硅微条，不只是微条之间的串扰，ASIC之间的串扰可能也很复杂。

当前CSC项目需要20 μm宽，1024通路，这是非常有挑战性的工作，在实际设计过程中金属电极是有阻抗的，对于1000多路的传感器压降问题需要考虑。

CMOS每层工艺需要填充，填充如何解决？电路和sensor的不同可能会导致凹陷，由此导致的良品率。

目前计划在电路部分挖掉衬底来实现sensor和电路的隔离，通过20 um 的DTI来实现隔离，需要仿真验证是否能够实现。

….

Next Plan

- The drafting of Silicon Tracker Ref-TDR has started.
- It’s ready to launch the 2nd review of the CMOS Strip Chip (CSC) project at institute level.

Agenda

2:00 PM → 2:10 PM 介绍

2:10 PM → 2:30 PM CSC 开发项目概况

CSC 开发项目概况v...

2:30 PM → 2:50 PM CSC 合作团队

CSC合作团队.pdf

2:50 PM → 3:10 PM CSC 传感器设计

CSC 传感器设计v2....

3:10 PM → 3:30 PM CSC 读出系统设计

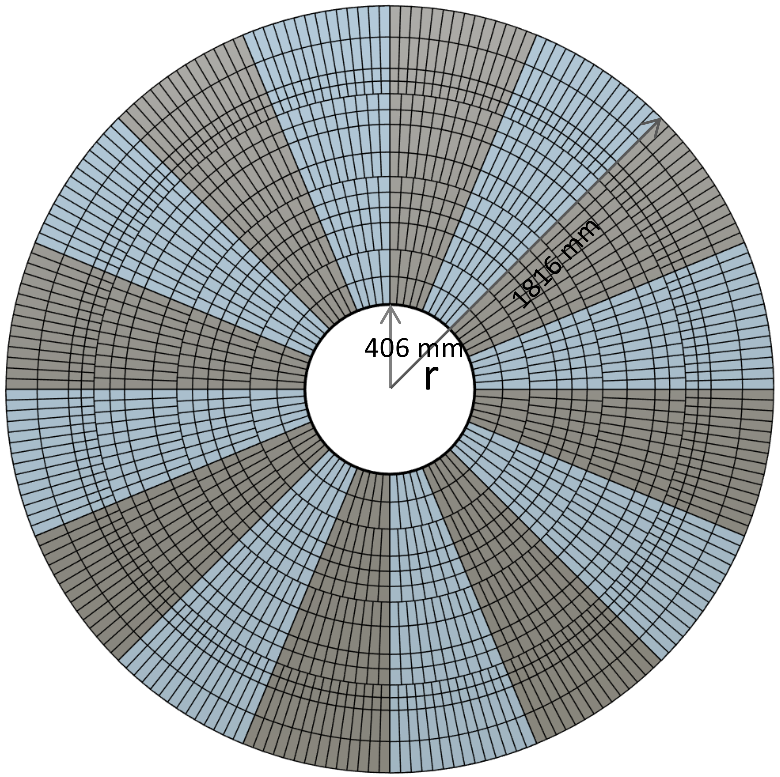
CSC 读出系统设计v...

3:30 PM → 3:50 PM CSC 测试系统设计

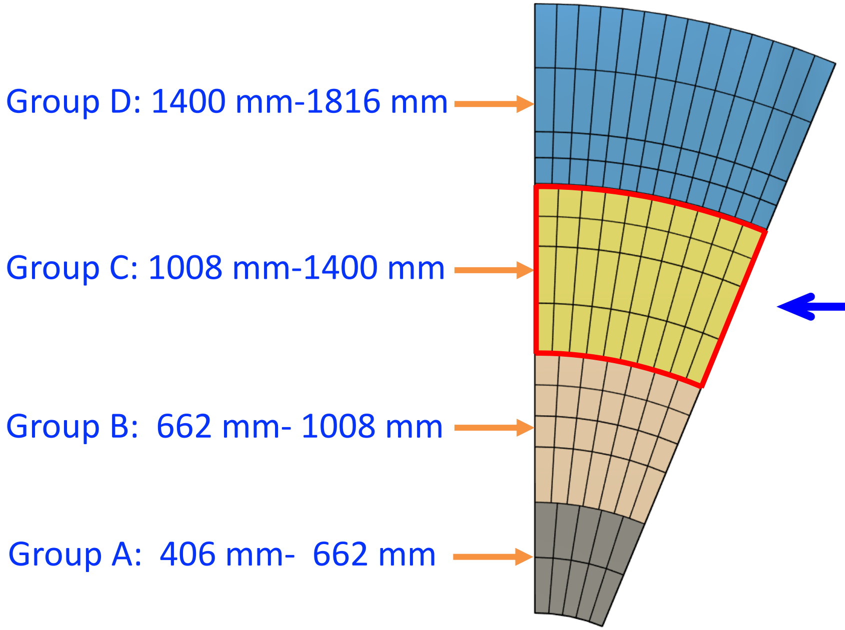
CSC测试系统设计.pdf

CEPC OTK Endcap Design (AC-LGAD Strips)

Endcap (16 sectors, 10 m^2):



1/16 Sector:

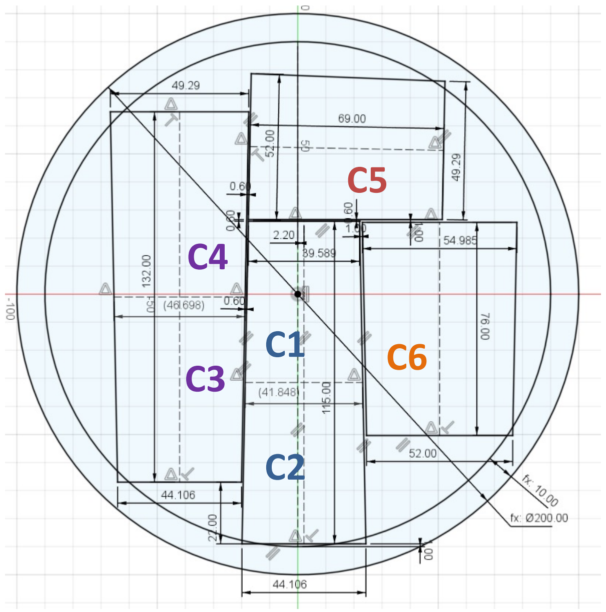

Group D: 1400 mm-1816 mm

Group C: 1008 mm-1400 mm

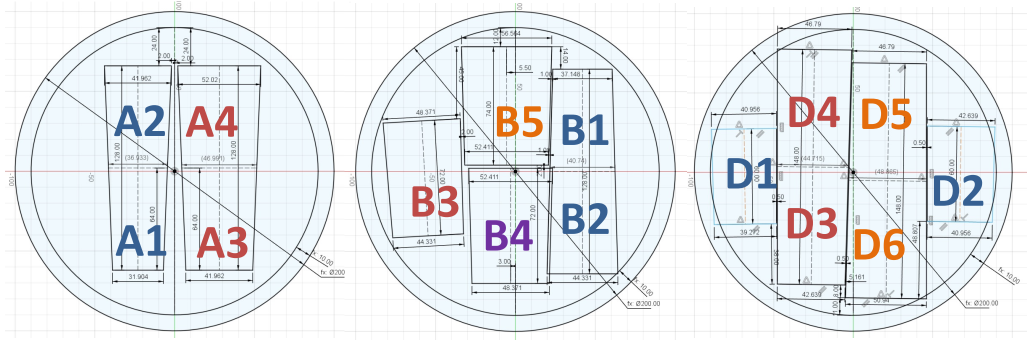
Group B: 662 mm- 1008 mm

Group A: 406 mm- 662 mm

Sensor: 8'' wafer (group C sensors)



8'' wafer (group A, B, D sensors)

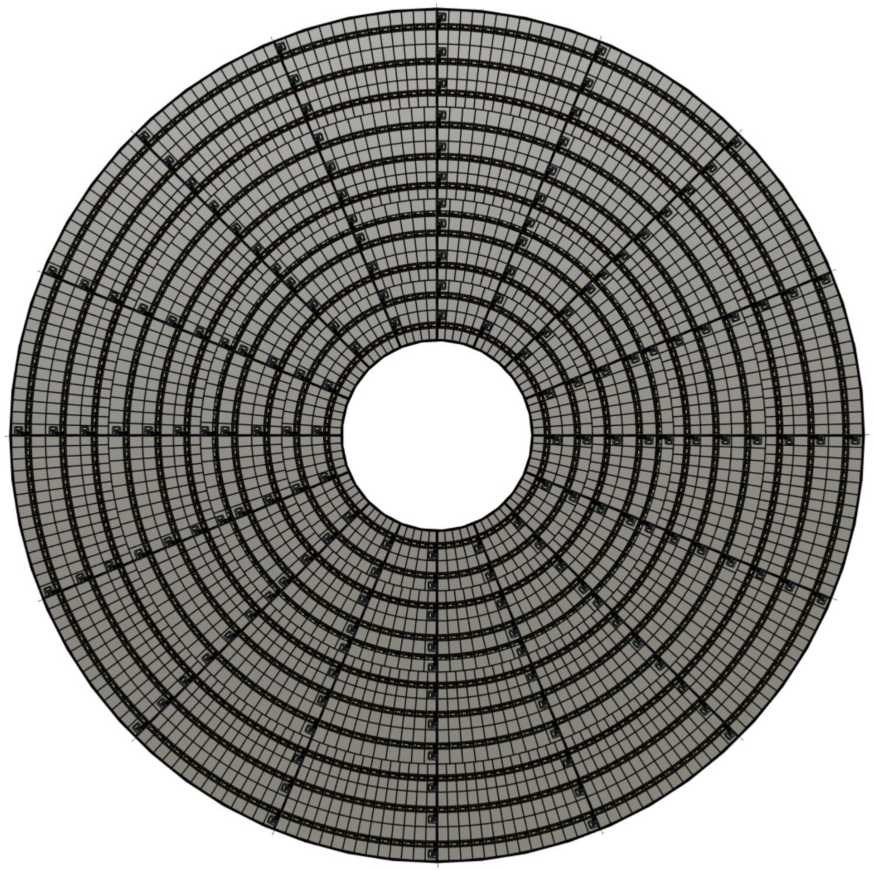


Maximum usage of silicon wafers

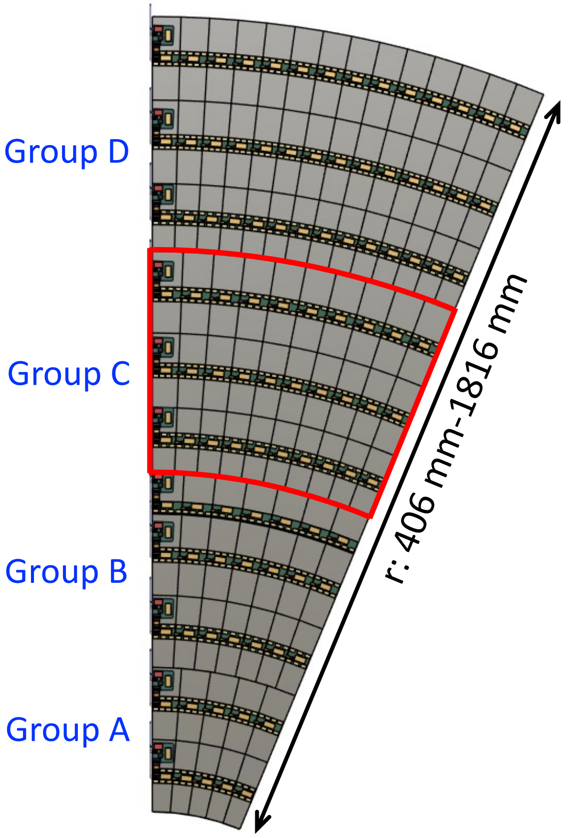
- OTK endcap consists of 14 rings, arranged into 4 groups.
- Each group contains 2-4 types of trapezoid sensors, which can be fitted to one 8'' silicon wafer.
- Each group of sensors is aligned to a 1/16 sector.
- The long sensor contains 2 sets of short-strip sensors.

CEPC OTK Endcap Electronic Components

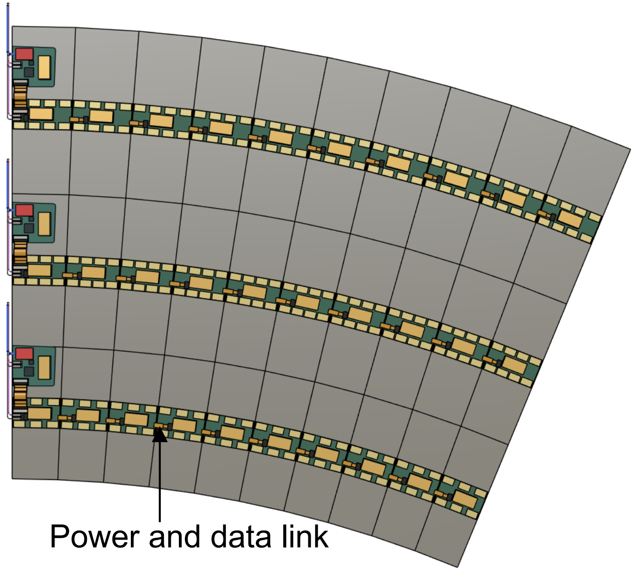
Endcap (16 sectors, 10 m^2):



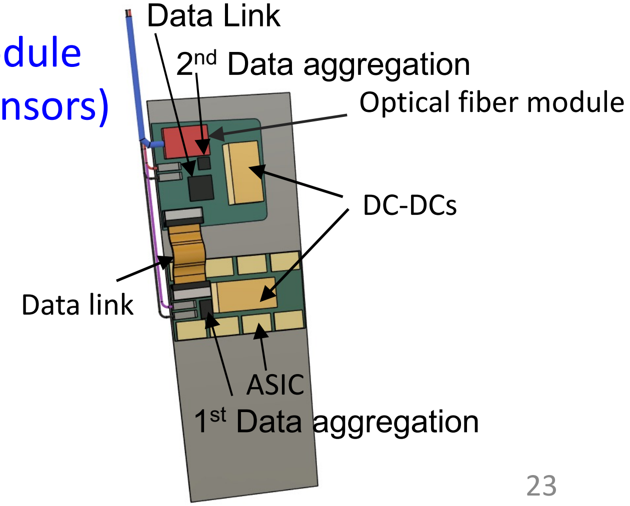
1/16 Sector:



Group C sensors:

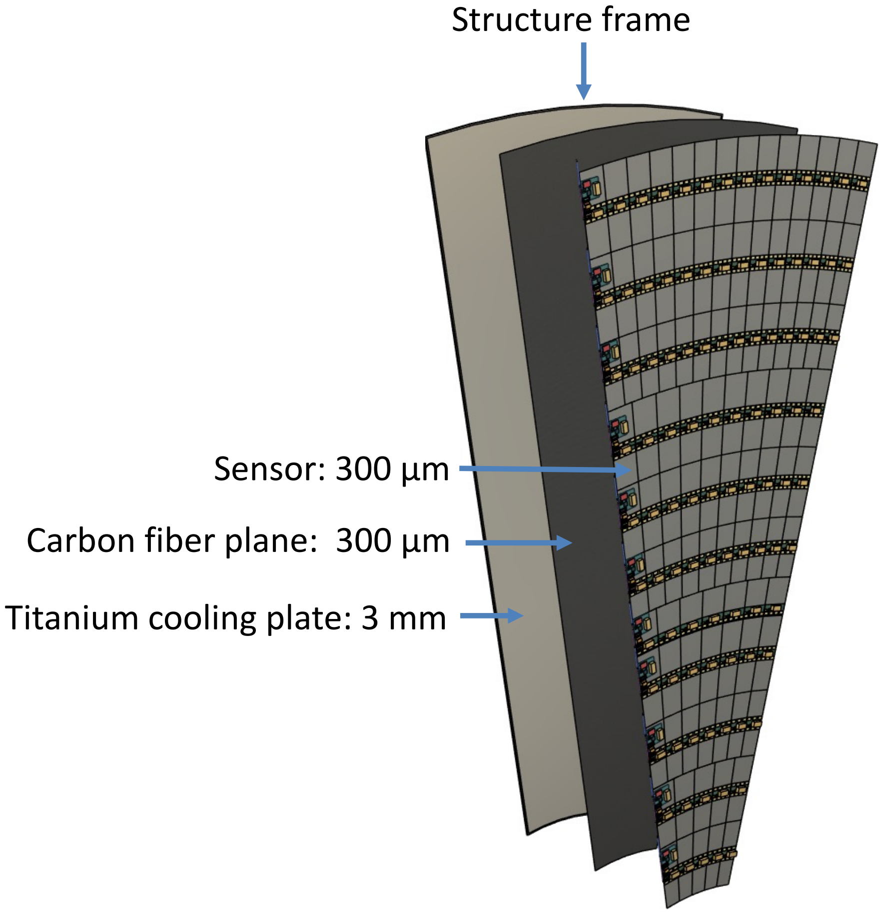


Module
(2 sensors)

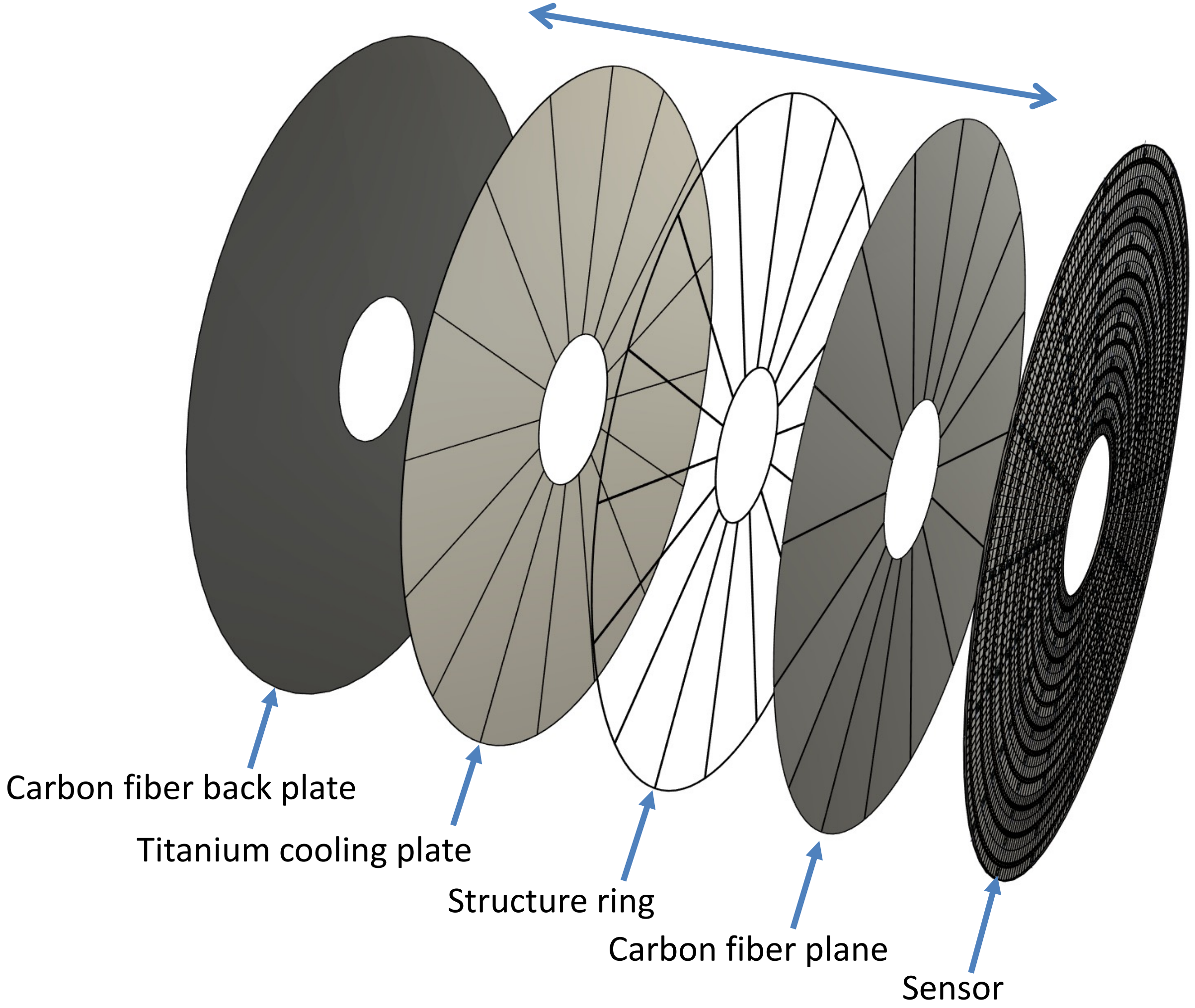


OTK Endcap Mechanical and Cooling Structure

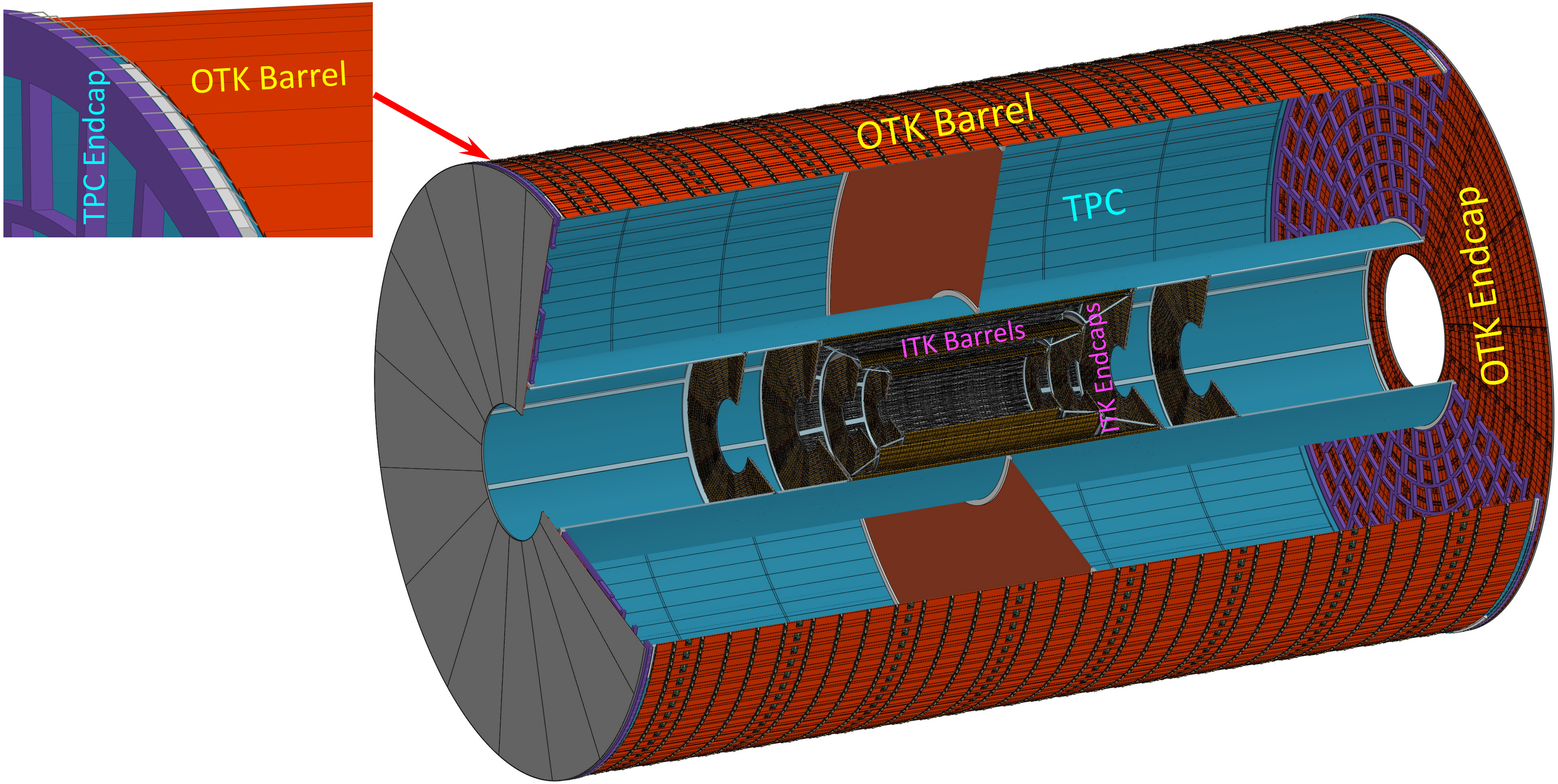
Endcap 1/16 sector structure:

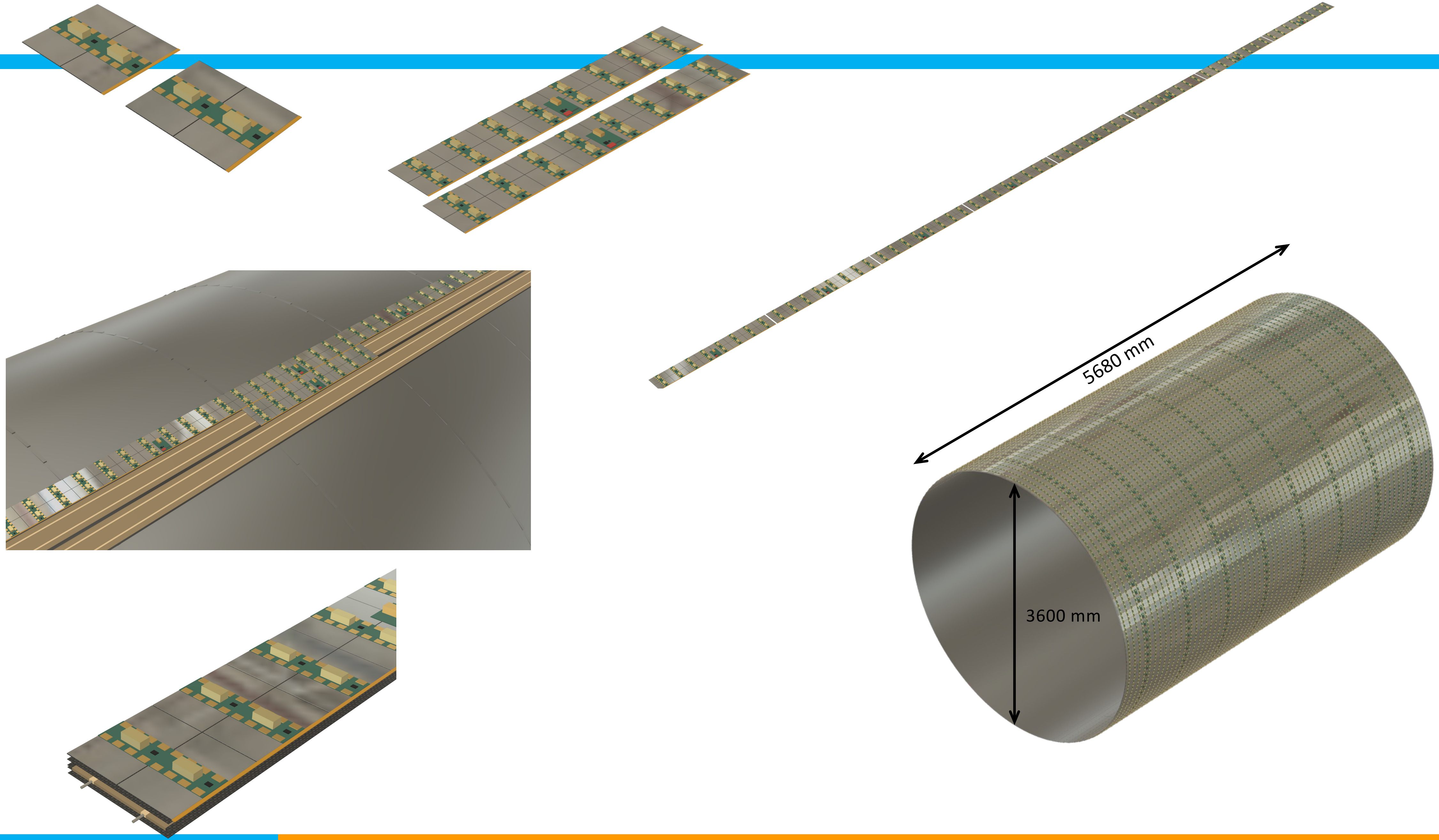


Endcap mechanical and cooling layout:



CEPC OTK Mechanics and Installation Design




5680 mm
3600 mm