Mechanical Design of CEPC HCAL

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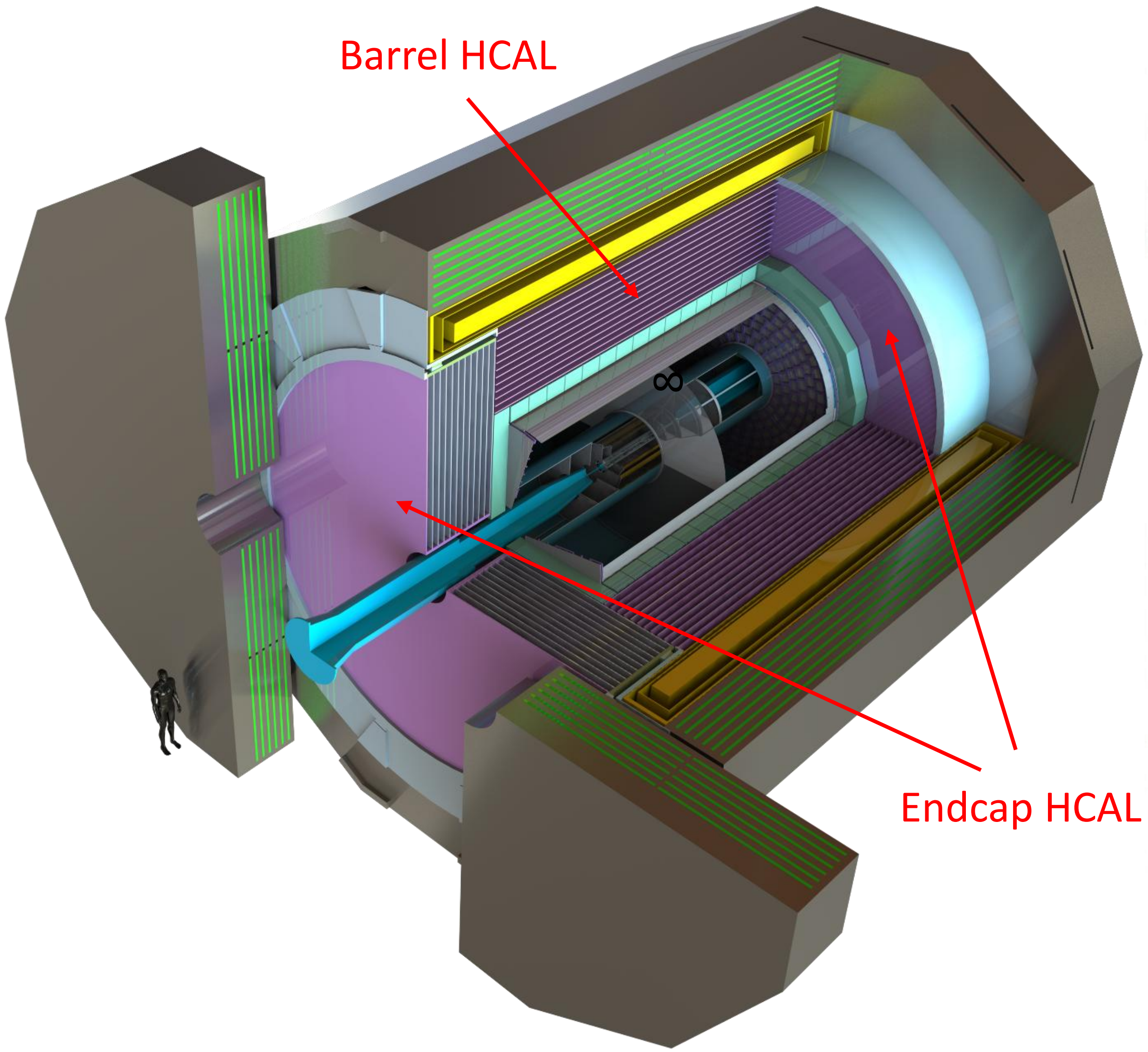
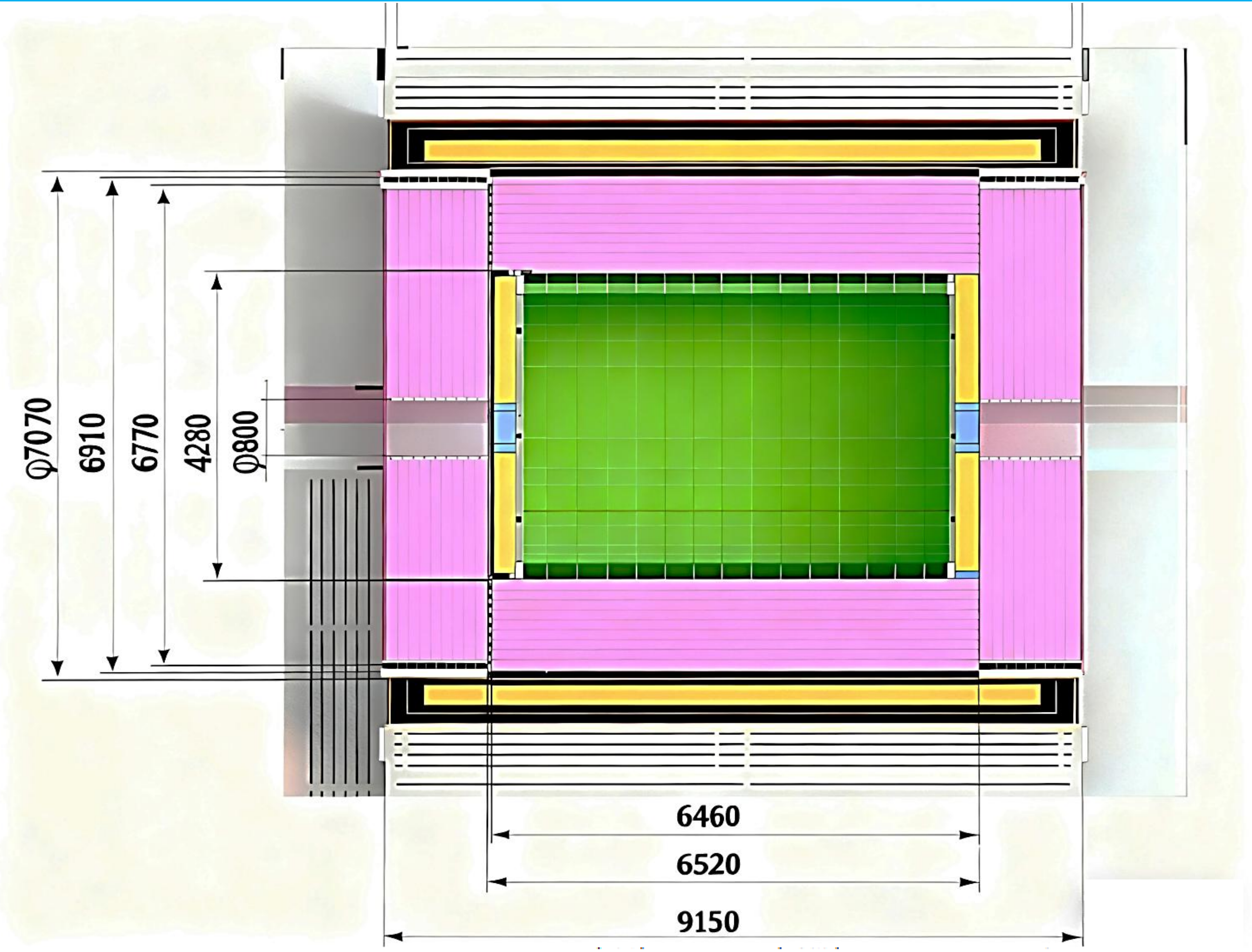
Outline

- Overview of HCAL structure
- HCAL mechanics design
  - **Barrel HCAL mechanics**
  - **Endcap HCAL mechanics**
  - **HCAL Cooling scheme**
- HCAL prototype and GS test structure

Overview of HCAL structure

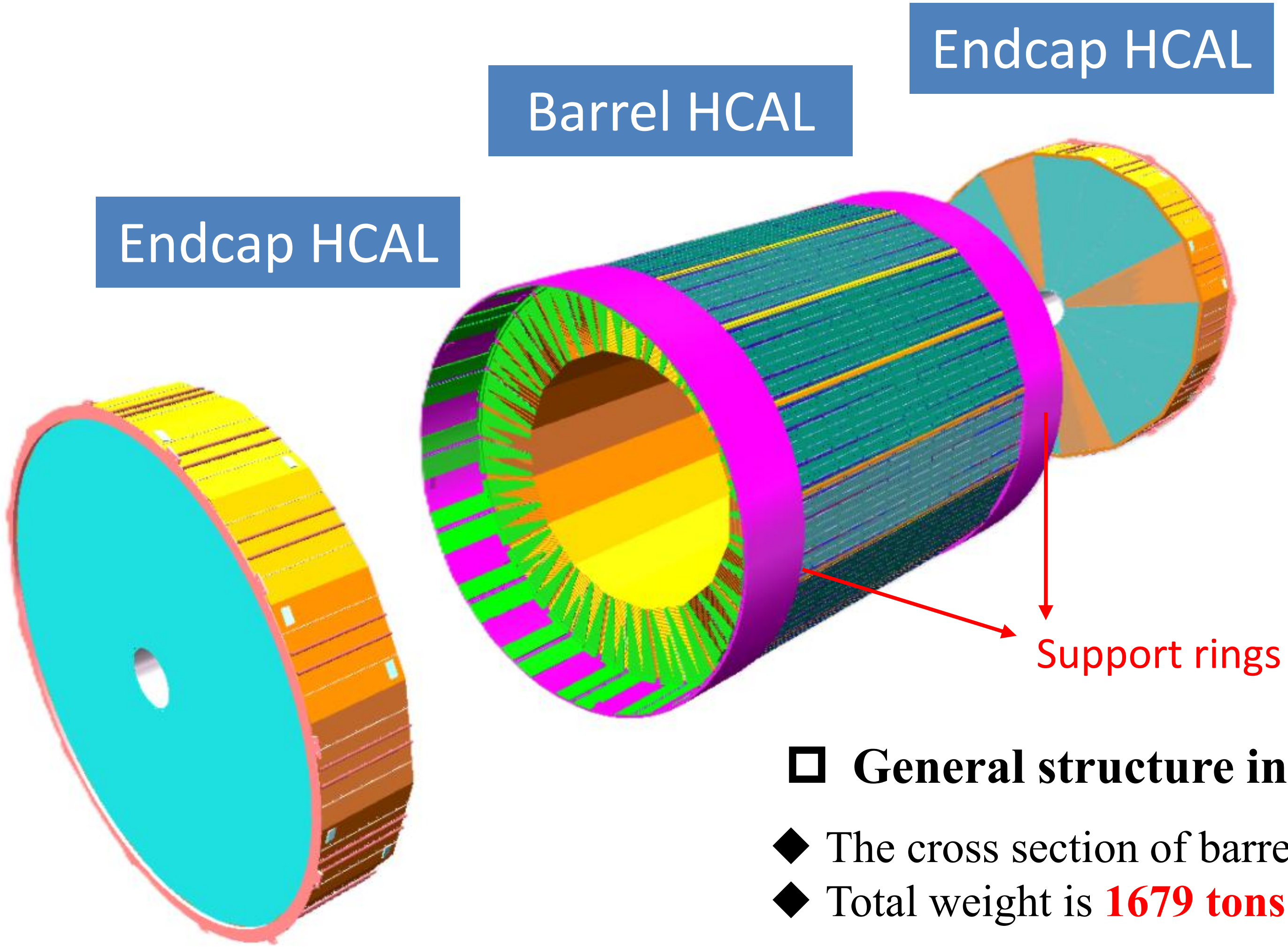




HCAL (barrel)	Glass scintillator + SiPM	r_{in} = 2140 $\lvert z\rvert \leq 3230$	r_{out} = 3455	48 layers, 16 sectors
HCAL (endcap)	Glass scintillator + SiPM	r_{in} = 400 $\lvert z_{in}\rvert$ = 3260	r_{out} = 3385 $\lvert z_{out}\rvert$ = 4575	$4 \times 4 \times 1$ cm^3 pixel 48 layers, 6 λ_I

HCAL mechanics design

Layout for all the HCAL components



Requirements:

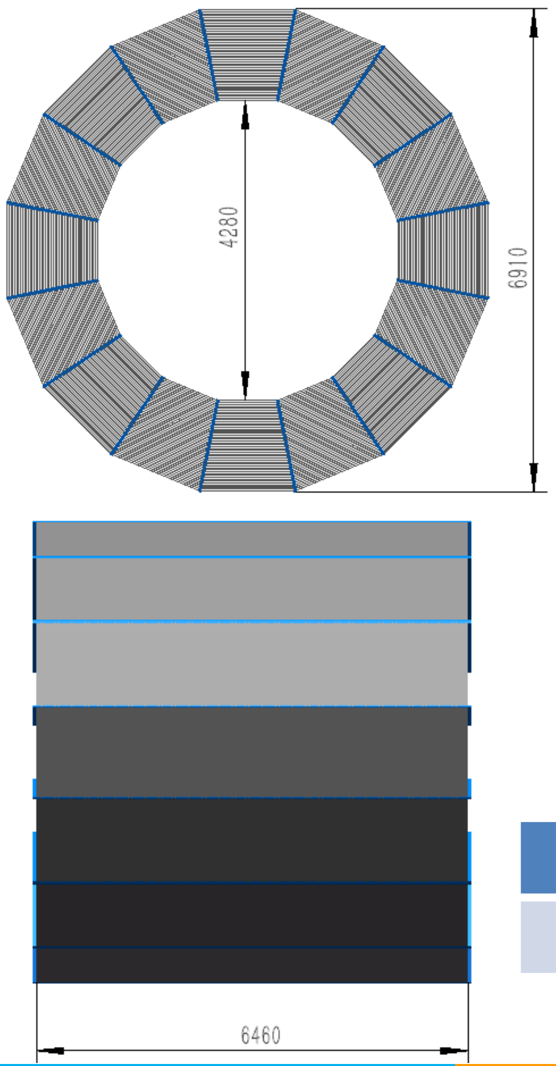
- The support structure zone is as lower as possible.
- The maximum stress of different materials need to be lower than their allowable stress level.
- The deformation of different materials need to be controlled so that there will be no broken parts under different conditions.
- Outer contour dimension tolerance need to be 0mm to -5mm and inner contour dimension tolerance need to be 0mm to +5mm.

General structure information:

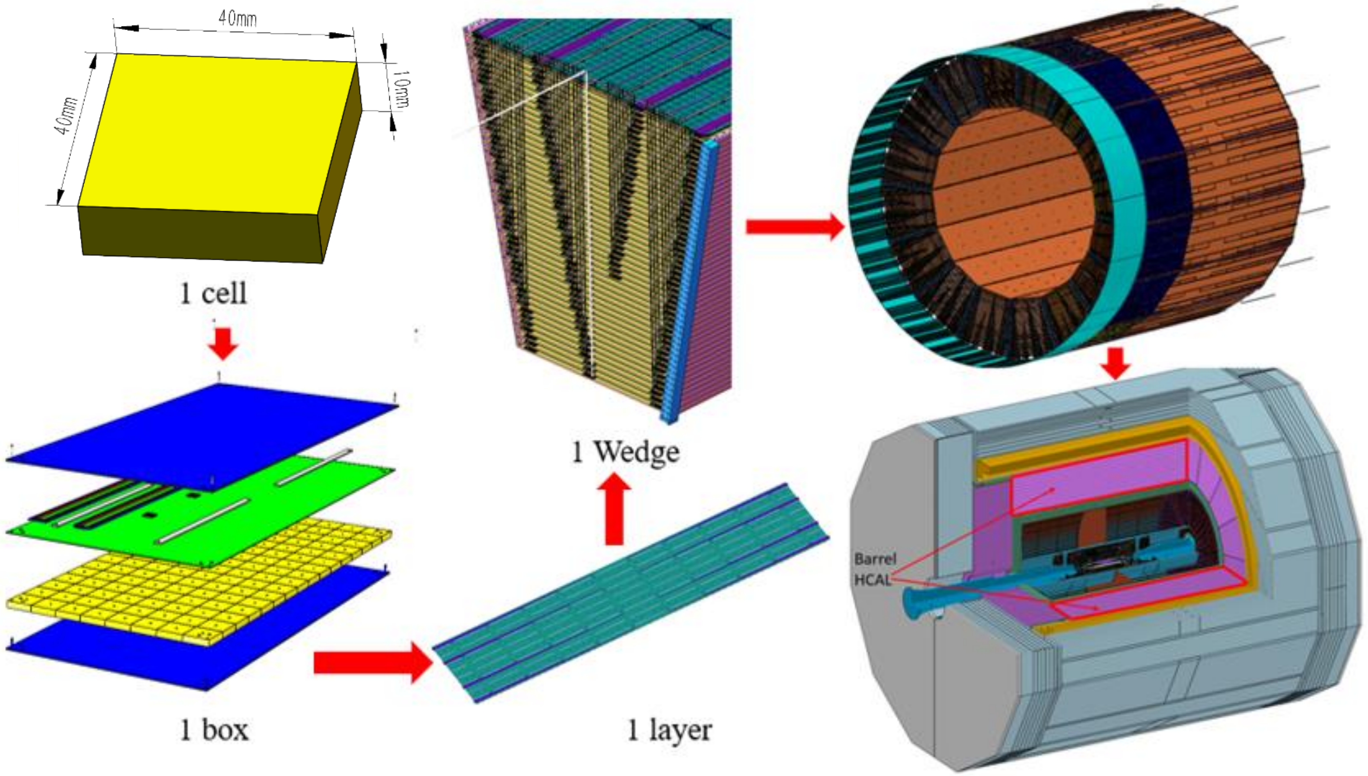
- The cross section of barrel HCAL is a regular hexdecagon
- Total weight is **1679 tons** and there are totally **5224960 glass scintillator**

Barrel HCAL mechanics

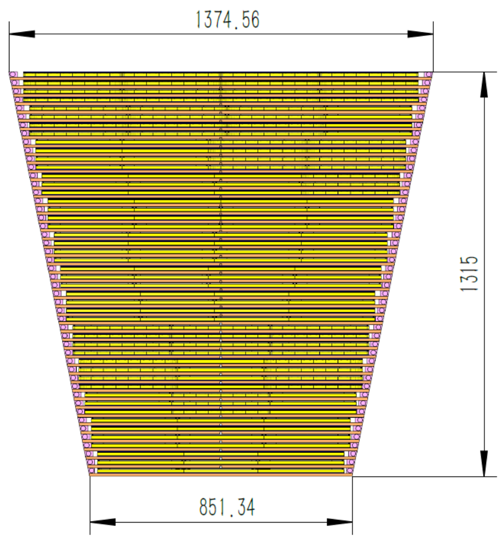
Main Structure



Integration of barrel HCAL structure



1 Wedge dimension

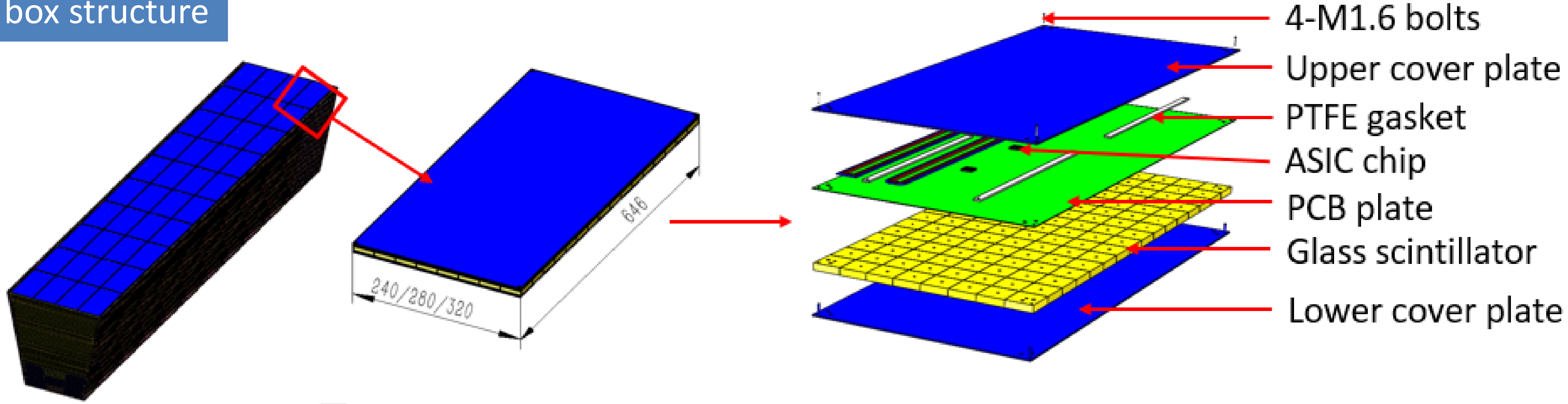


	Cell	Box	Layer	Wedge
Quantities	3212800	27840	48*16=768	16

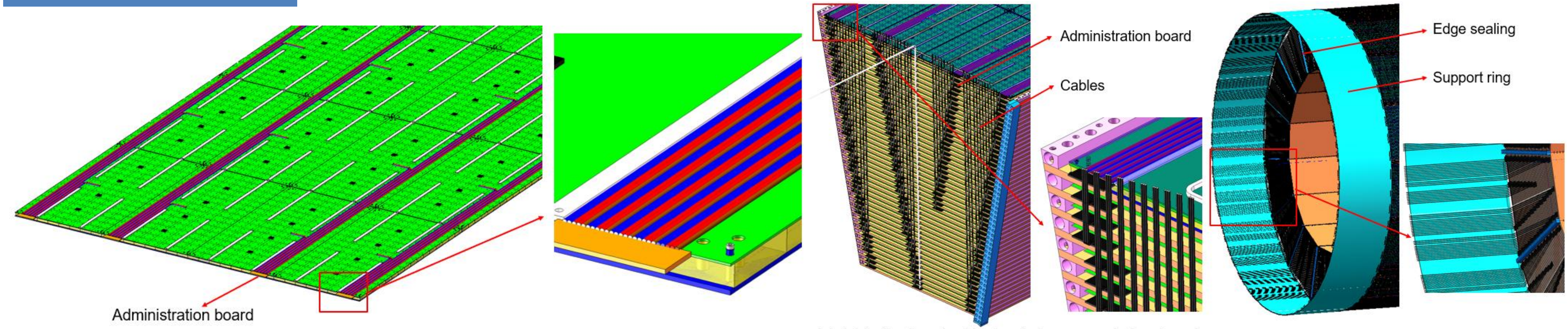
Total weight: 955 tons

Barrel HCAL mechanics

One box structure

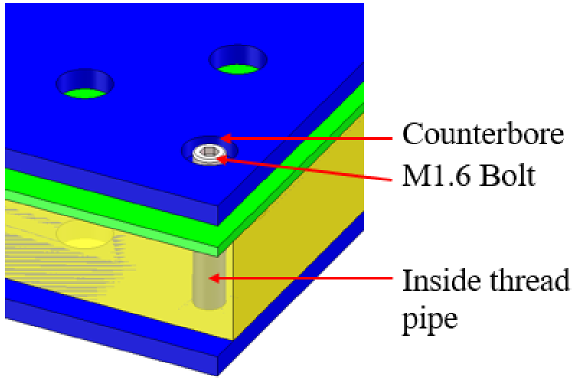


Cable routing scheme

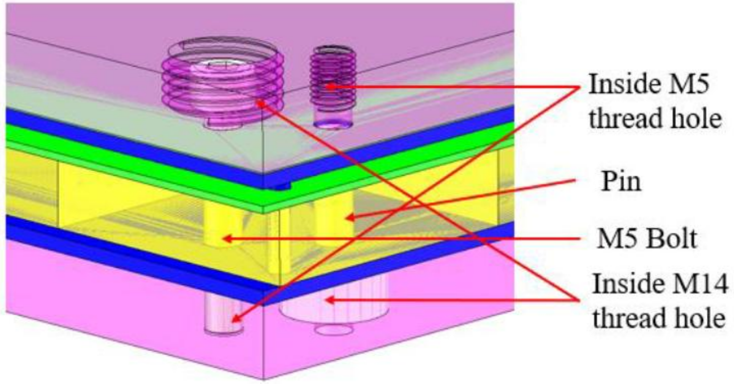


Barrel HCAL mechanics

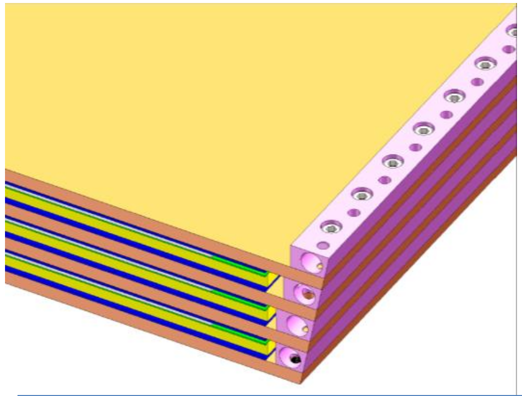
Connection within one box



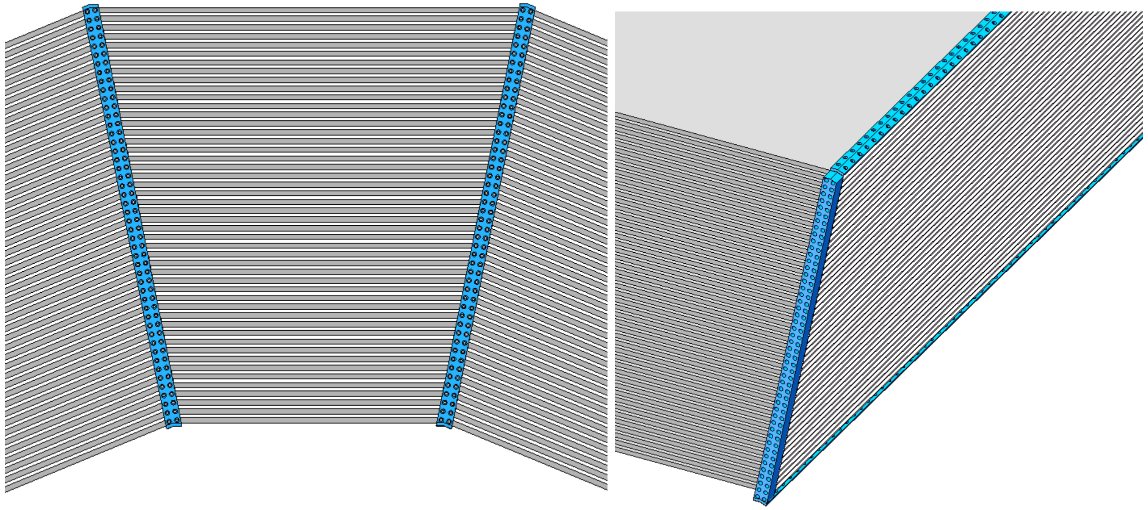
Connection between box and absorber layer



Connection between neighbor layers

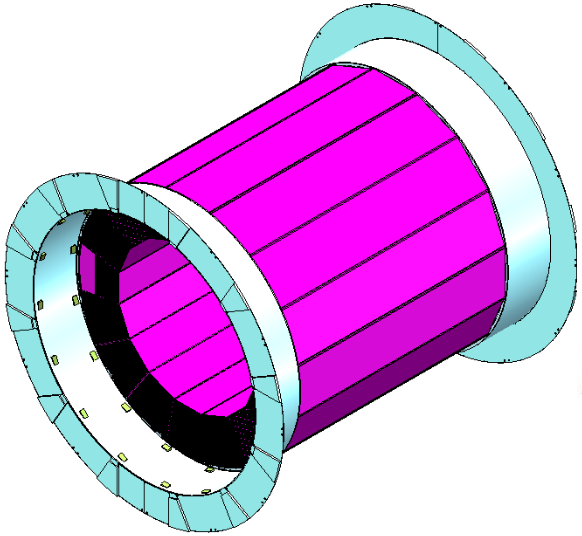


Connection between two wedges

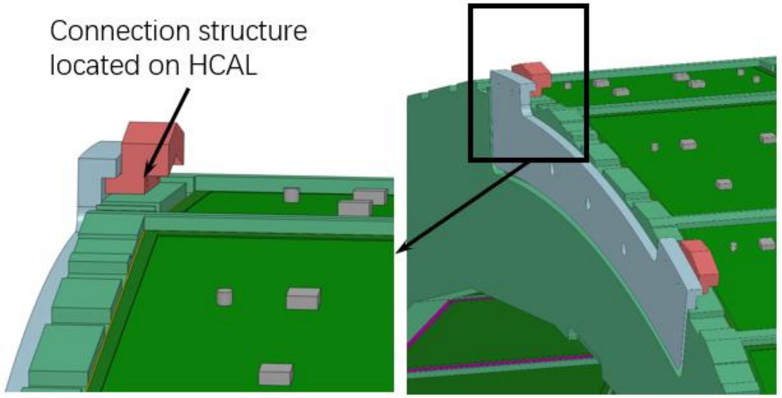


Edge sealings

Connection between Barrel HCAL and support rings



Connection between Barrel HCAL and Barrel ECAL



Barrel HCAL mechanics

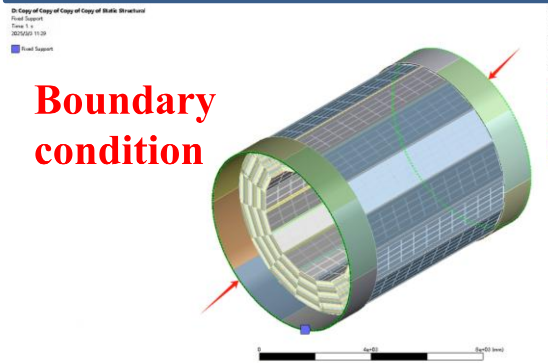
FEA result of barrel HCAL

Stress and deformation of barrel HCAL under different conditions

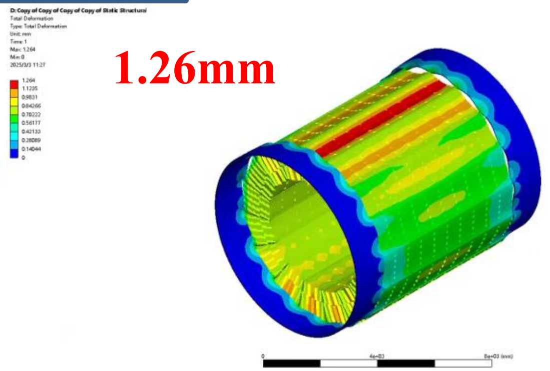
Parameter	Stress	Deformation
One wedge assembling condition	24.7MPa	0.33mm
16 wedges assembling condition	190MPa	0.66mm

Barrel ECAL connection condition

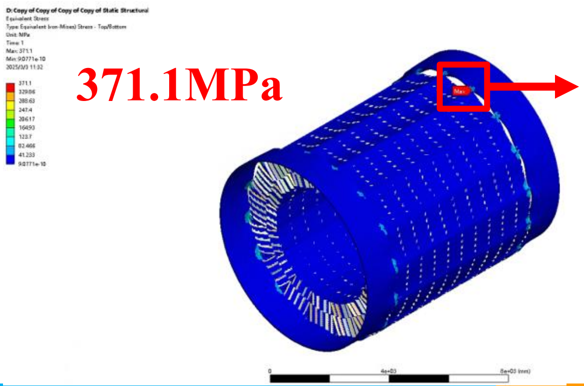
Boundary condition

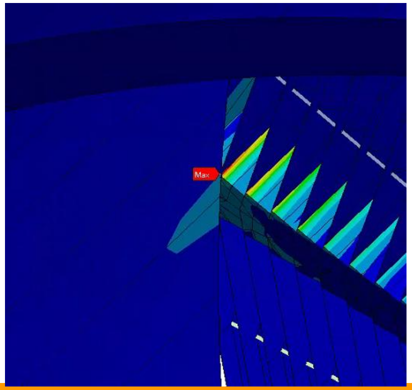


1.26mm



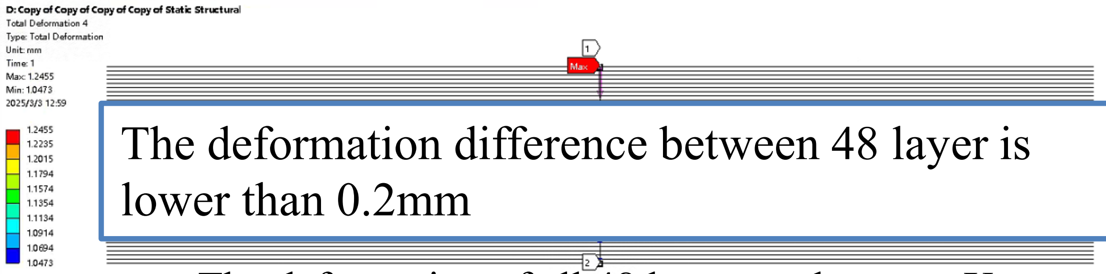
371.1MPa





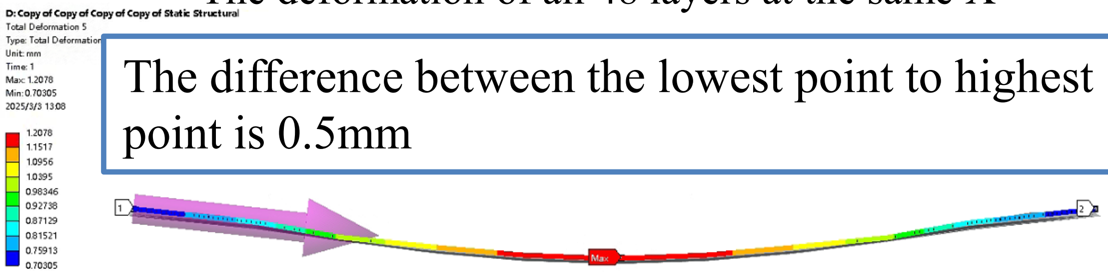
Changing the trapezoid beam from stainless steel to titanium alloy

Active layer space analysis



The deformation difference between 48 layer is lower than 0.2mm

The deformation of all 48 layers at the same X

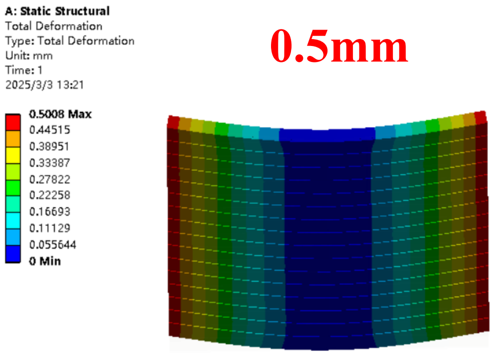


The difference between the lowest point to highest point is 0.5mm

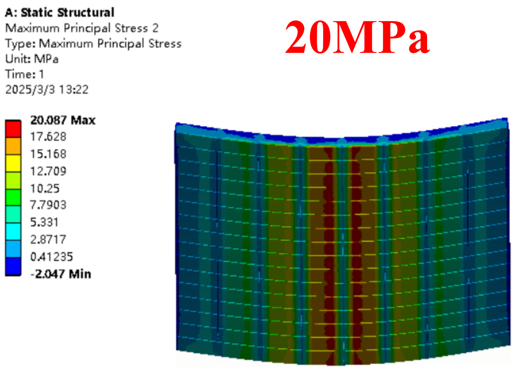
Deformation within one layer

GS analysis

0.5mm

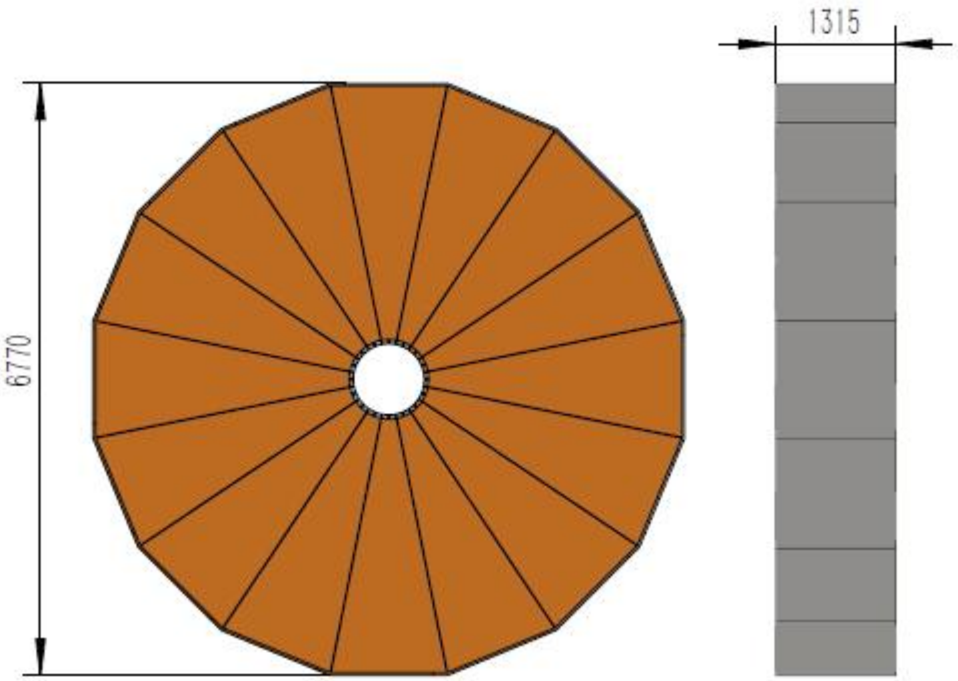


20MPa

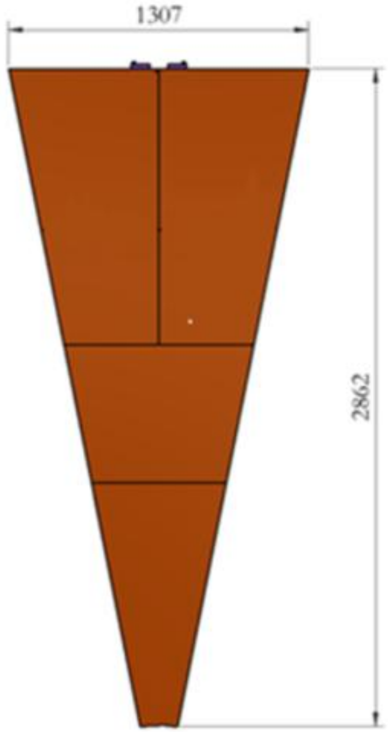


Endcap HCAL mechanics

Main Structure

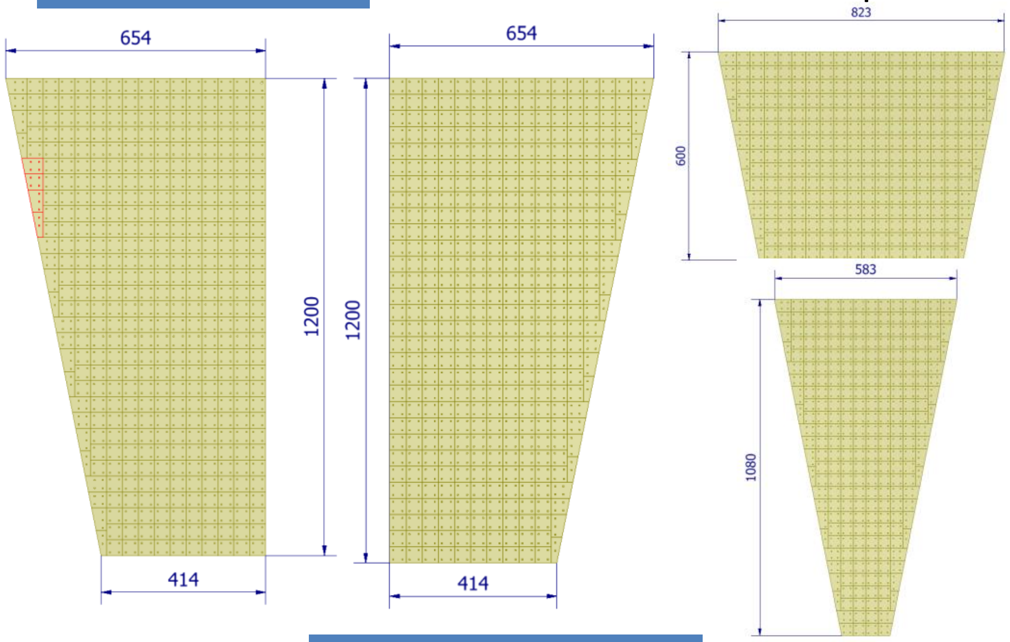


Boxes in one layer

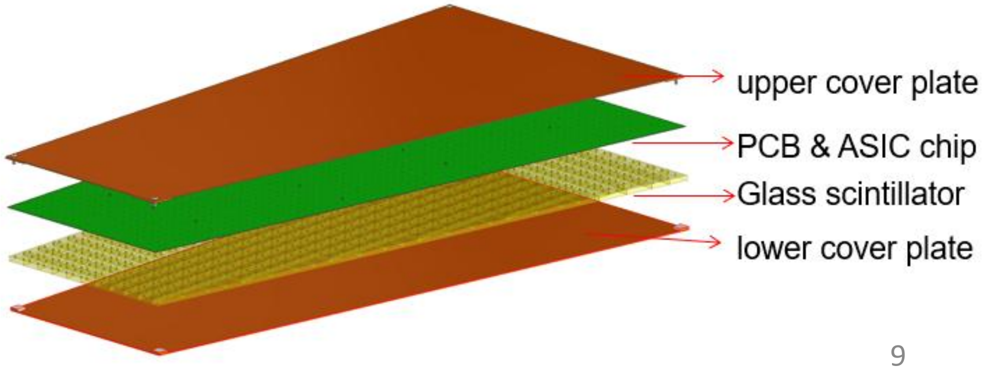


4 types boxes

4 kinds of abnormal shape GS



One box structure

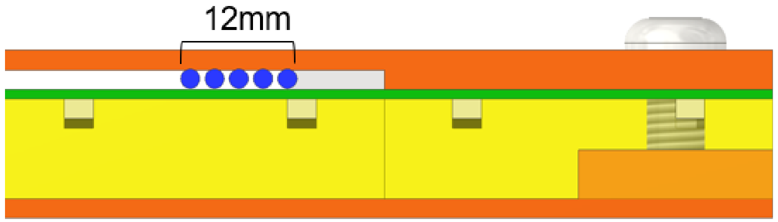


	Cell	Box	Layer	Wedge
Quantities	1006080*2	3072*2	48*16*2	16*2

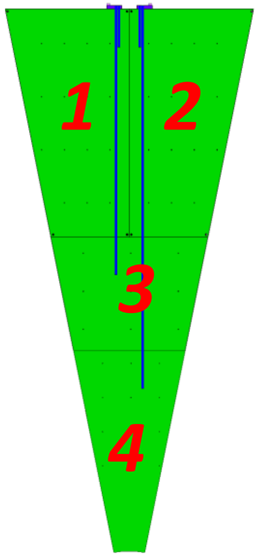
Total weight: 362*2=724 tons

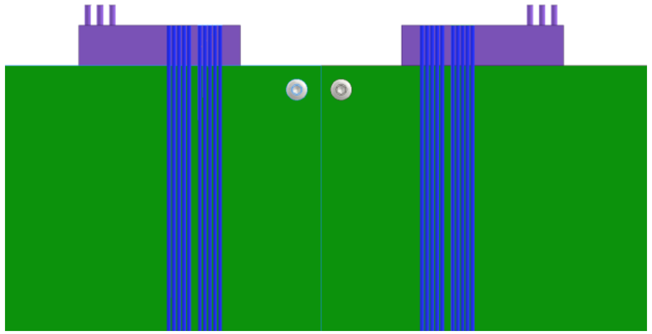
Endcap HCAL mechanics

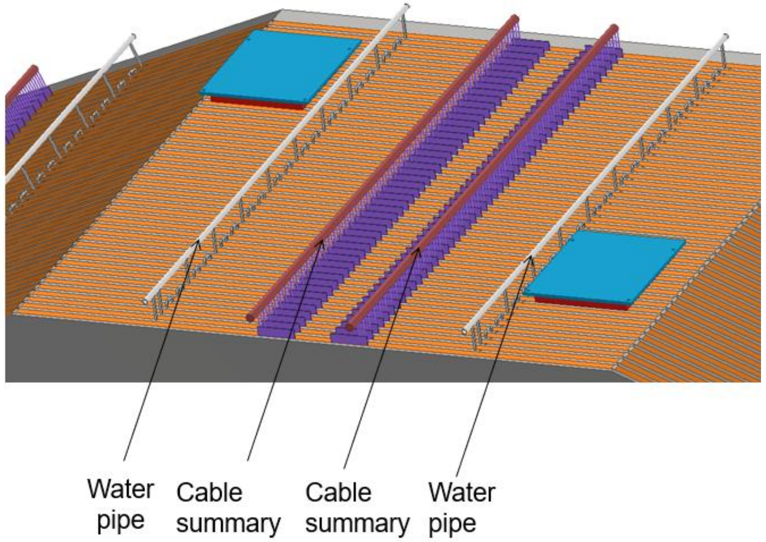
Cable routing scheme



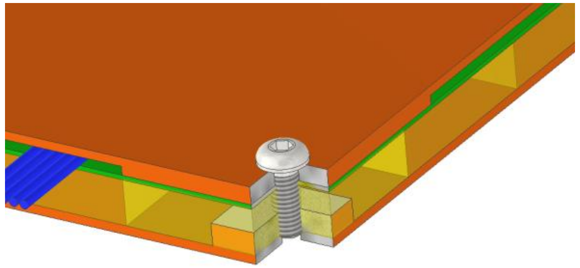
- 5 cables in one box
- Cable diameter 2mm



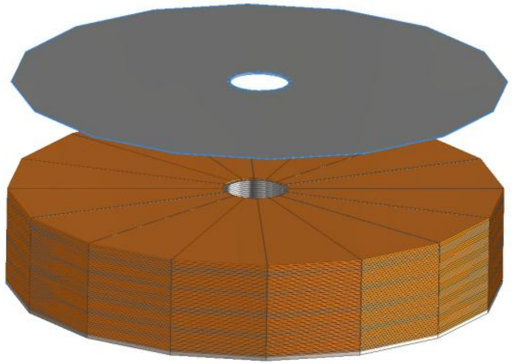




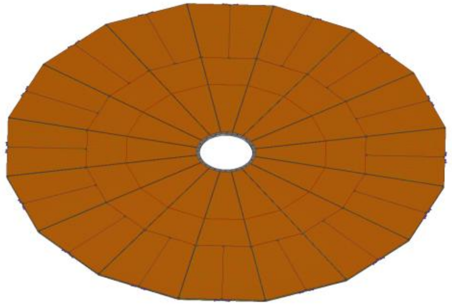
Connection within one box



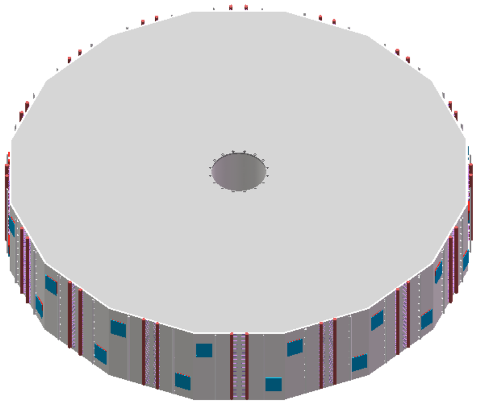
Connection between layers



Structure between neighbor wedges

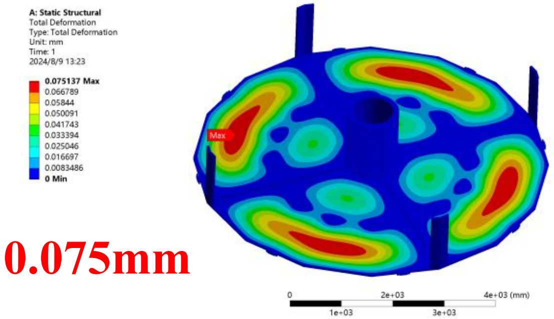


Connection between end HCAL and support rings

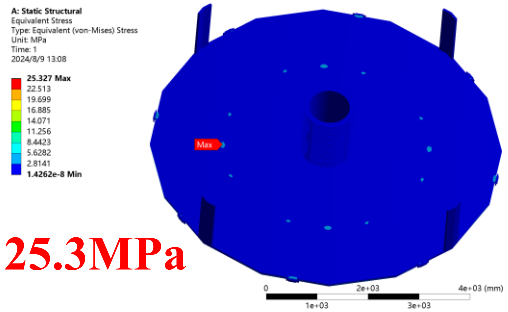


Endcap ECAL mechanics

- FEA result

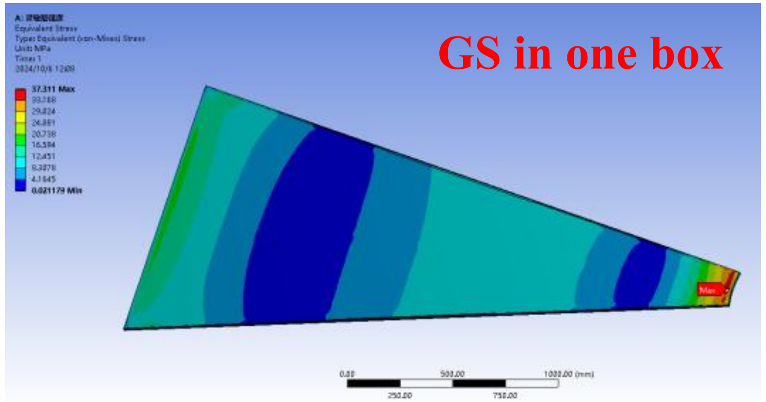


0.075mm

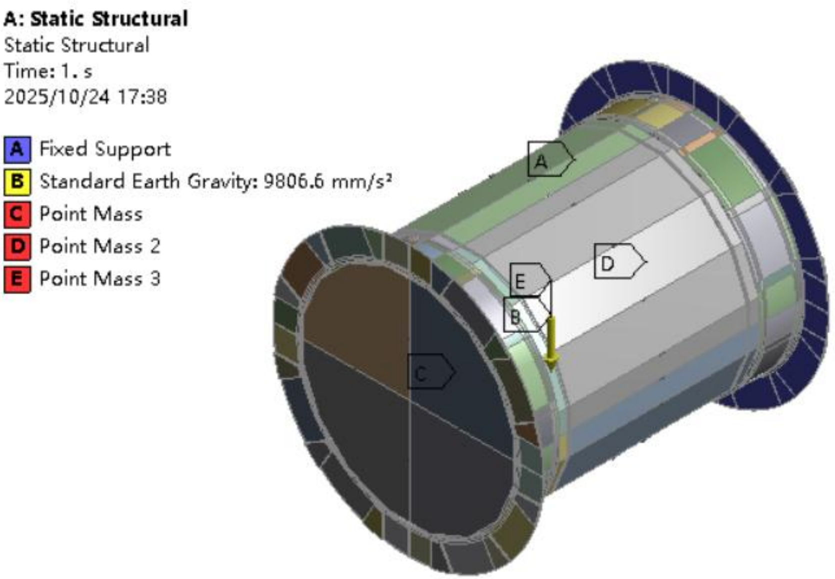


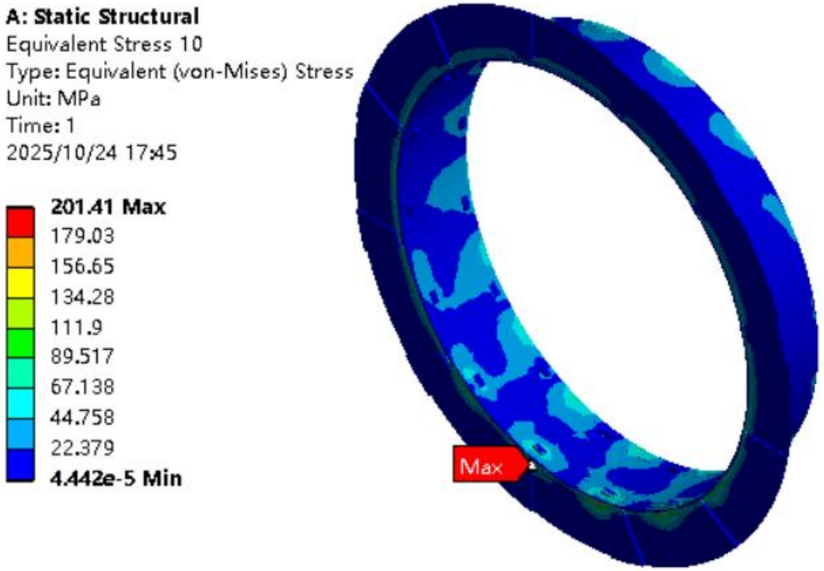
25.3MPa

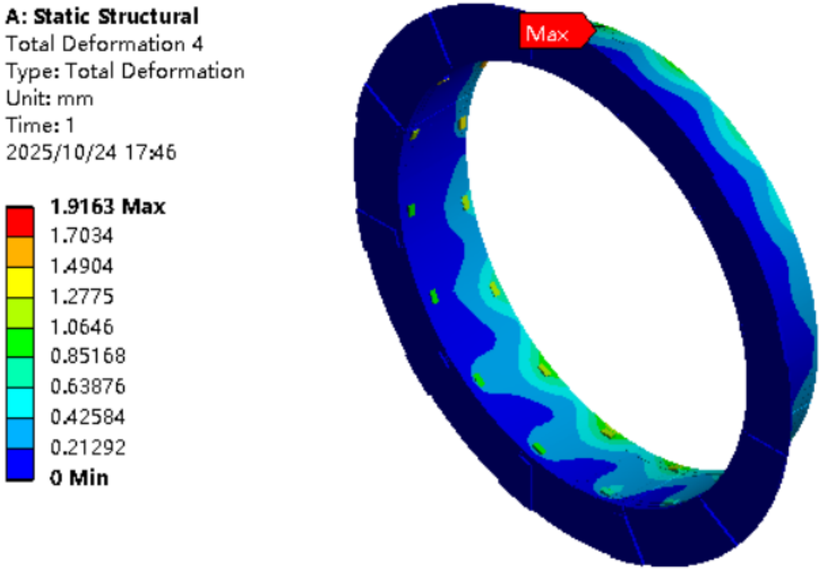
Absorber structure during self-gravity condition



- The max principal stress of GS is 32MPa which is lower than its allowable stress 60MPa







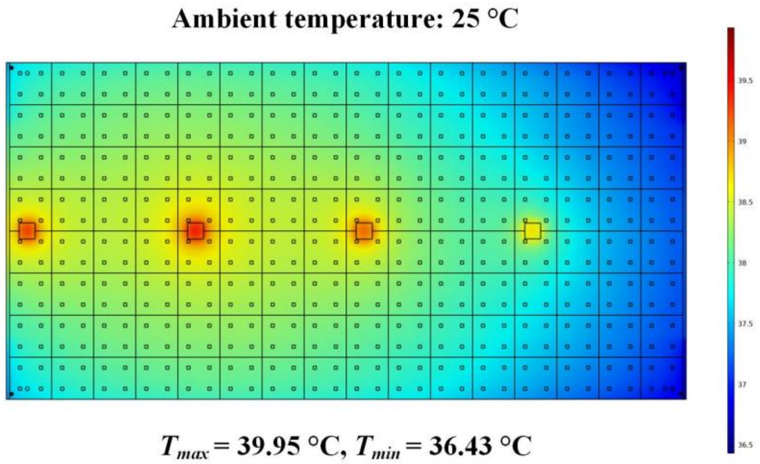
Connection parts are made of SS (18Mn18Cr)

1.5 safety factor

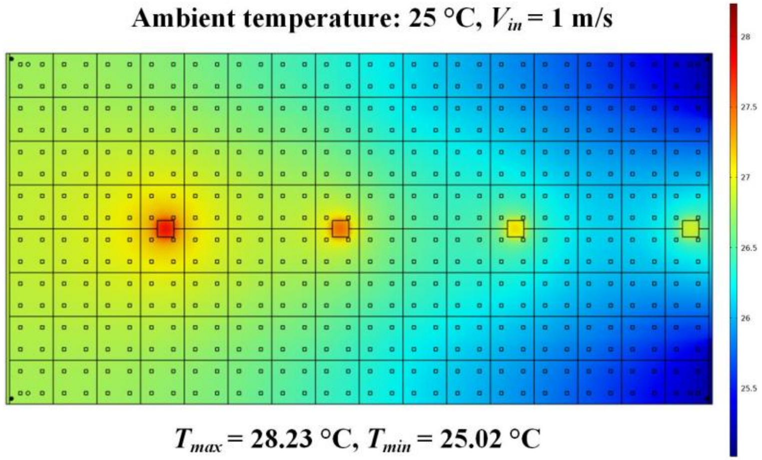
HCAL cooling system

Cooling scheme definition

The temperature error of different SiPM need to be controlled less than ±1.5℃



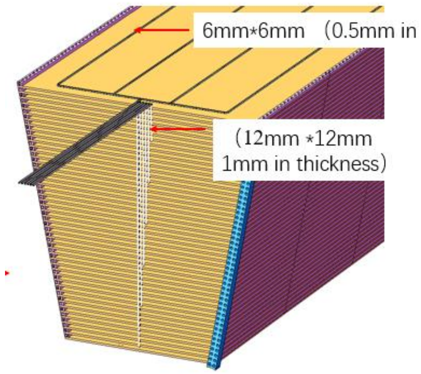
FEA result of thermal performance of **natural convection**

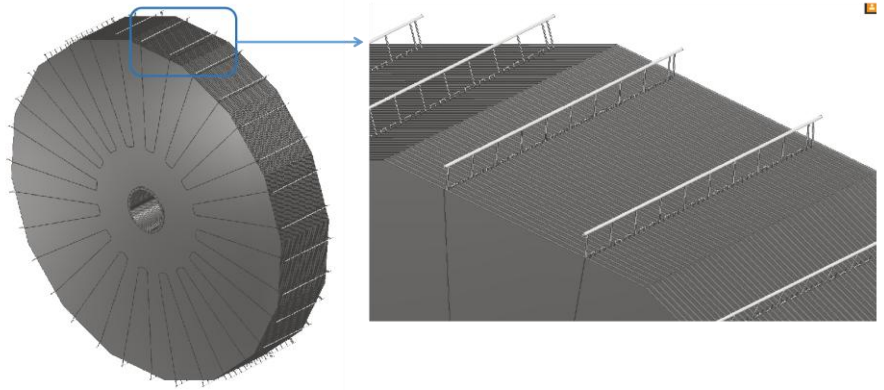


FEA result of thermal performance of **air-cooling**

- ◆ The excessively narrow interlayer gaps significantly reduce the efficiency of natural convection and air cooling, thereby failing to address the thermal management demands.
- ◆ **It is imperative to adopt liquid cooling technology to ensure efficient heat dissipation and temperature uniformity.**

Cooling structure of barrel and end cap HCAL



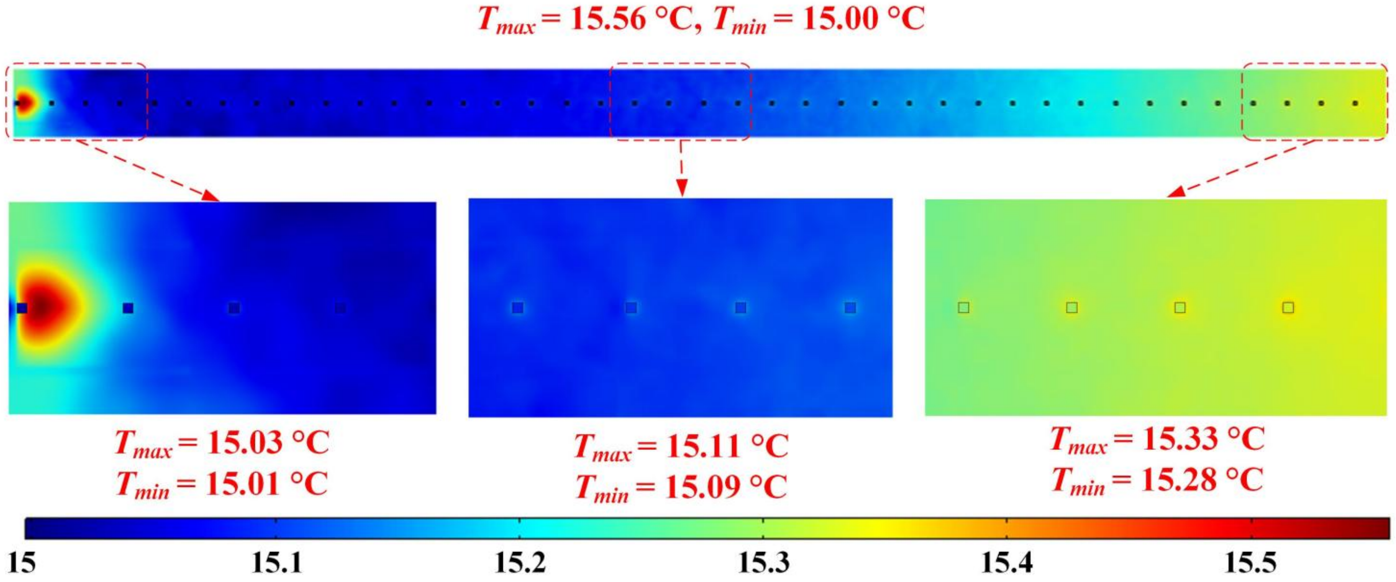


- 4 pipes in each layer in parallel
- 8 layers gather in one pipe in parallel
- One end is inlet and another end is outlet

- 1 pipe in each layer for one wedge
- 5 layers gather in one pipe in parallel for one wedge
- There is one inlet and outlet for each region.

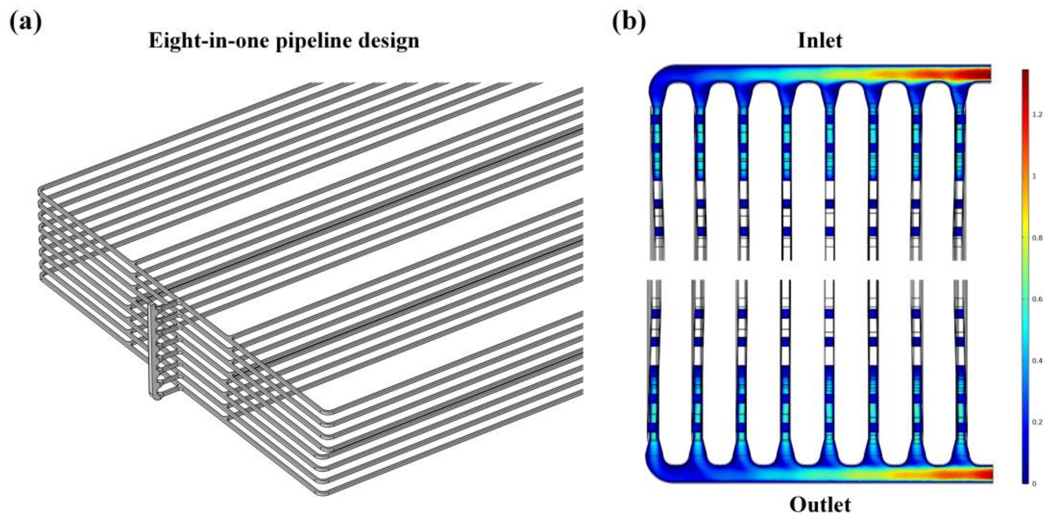
HCAL cooling system

FEA simulation of cooling system



Temperature distribution of the HCAL through liquid cooling

- Inlet temperature is 15 °C with a flow rate of 0.005 kg/s (corresponding to an inlet velocity of 0.1 m/s).
- **Effectively maintaining the temperature rise below 0.6 ° C.**
- **The maximum temperature variations of chips under the same modules were under 0.1 ° C**

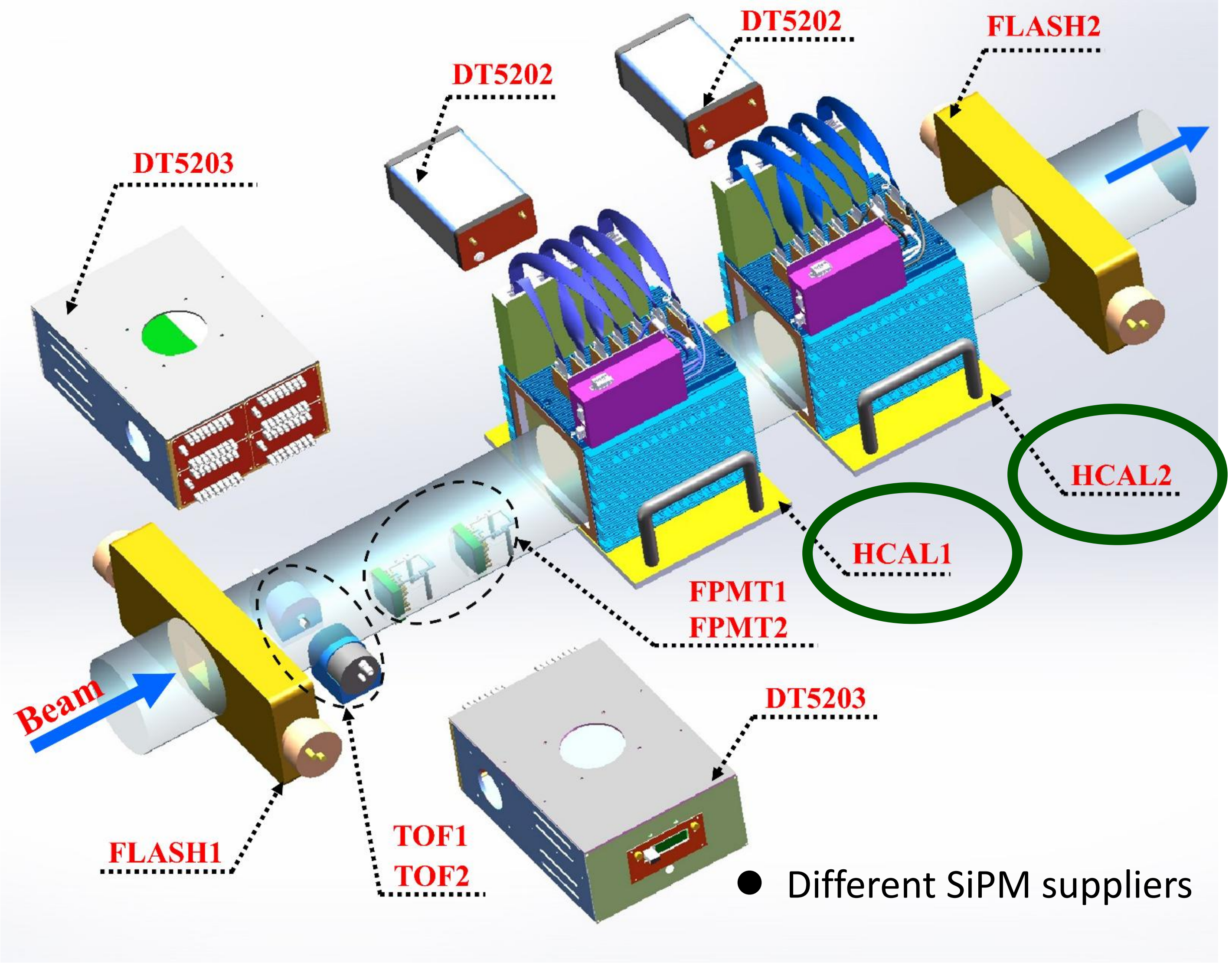


(a) Eight-in-one design of flow pipe
(b) Flow velocity distribution across different layers

- **Achieving a uniform flow velocity distribution across different layers**
- **The pipe resistance and length of endcap HCAL is smaller than barrel HCAL, so the same scheme can also meet our requirement**

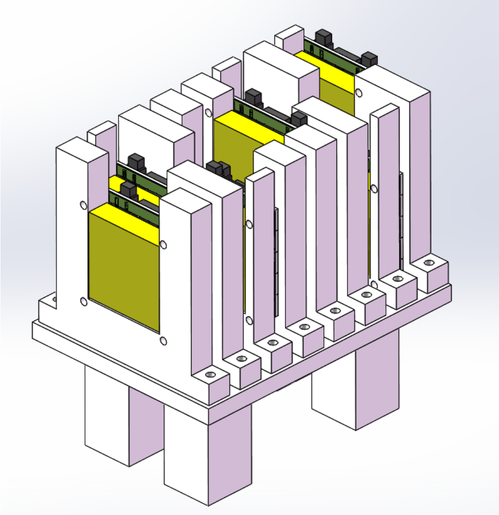
HCAL prototype and GS test structure

- **Beam test for two HCAL prototypes**



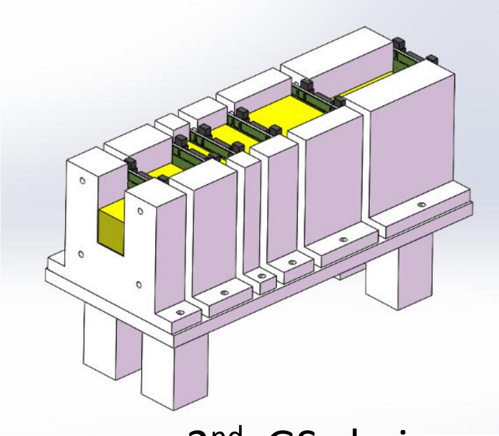
- Different SiPM suppliers

- **Beam test for GS**



1st GS chain

- 7 GS with same dimension
- Beam goes through different position for each GS

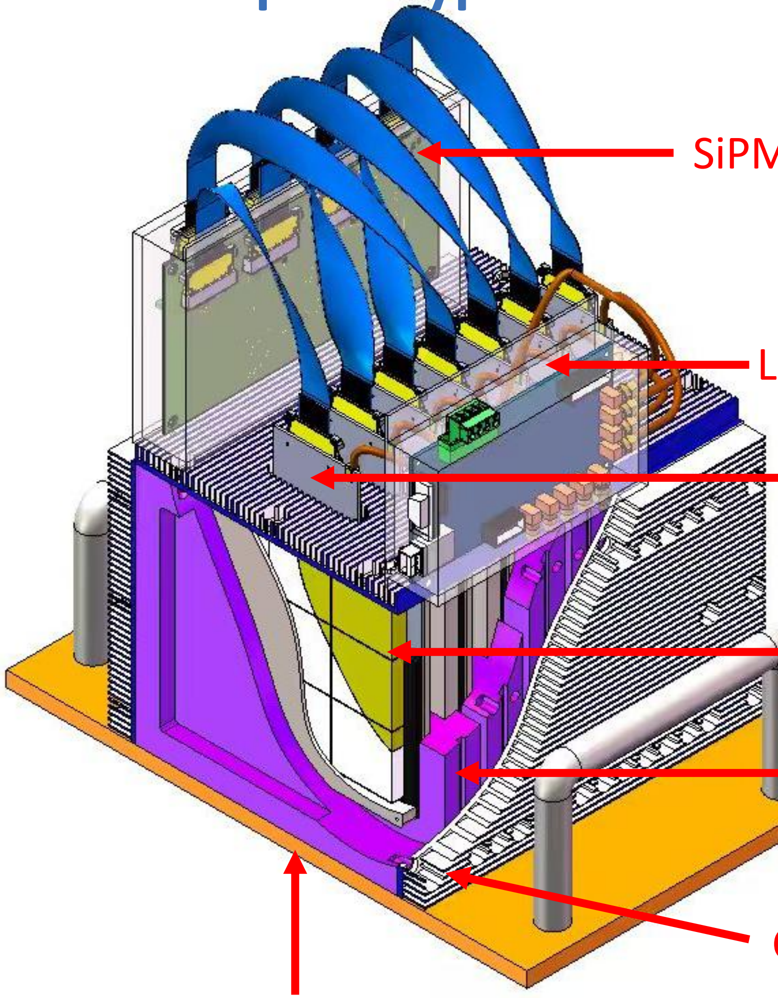


2nd GS chain

- 6 GS with different dimensions
- Beam goes through the center of each GS

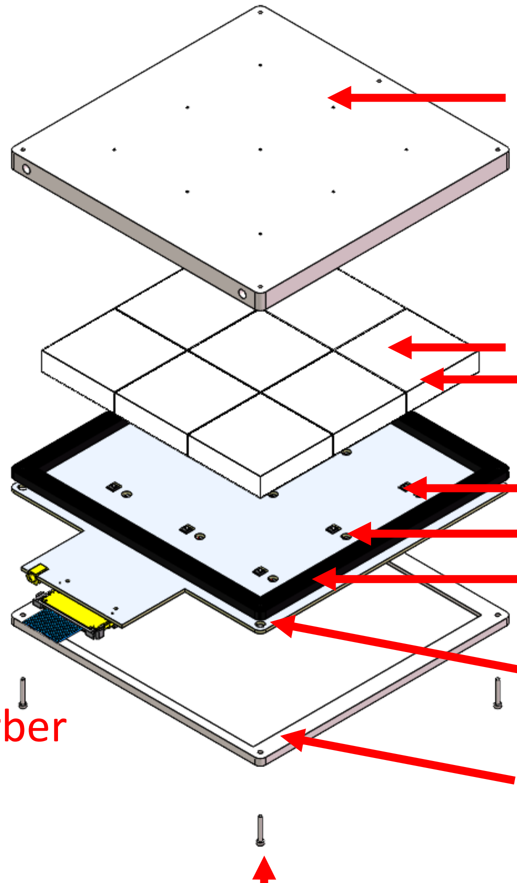
HCAL prototype and GS test structure

HCAL prototypes



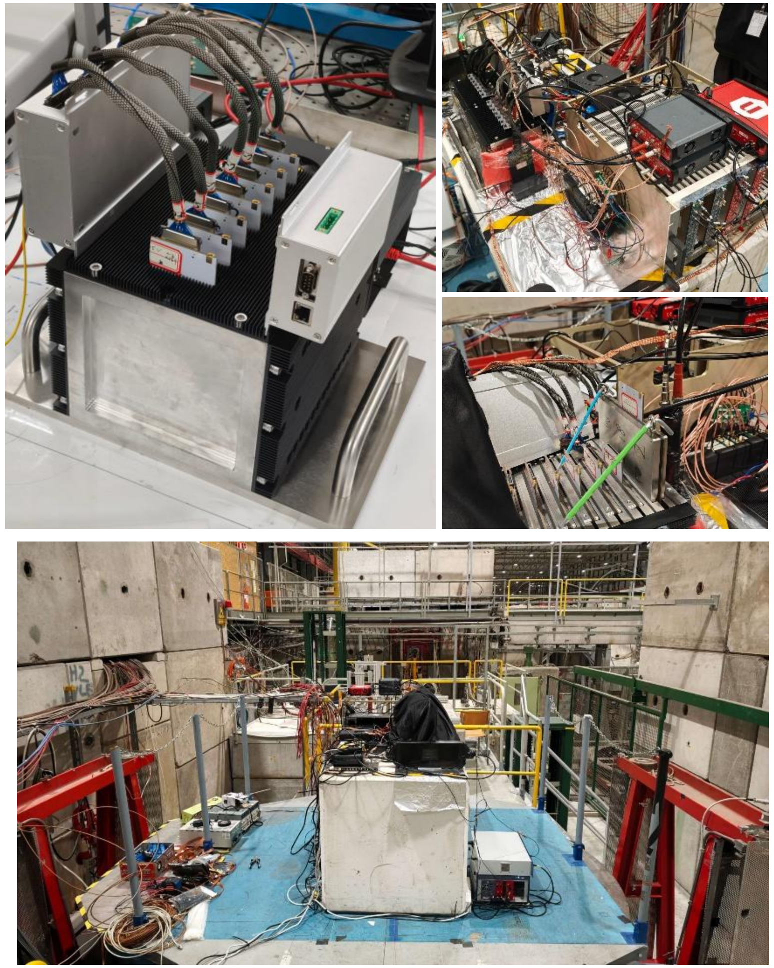
- 7 Boxes in one prototype

One box



- 9 GS in one box

Real prototype and beam test



- @CERN

Thanks