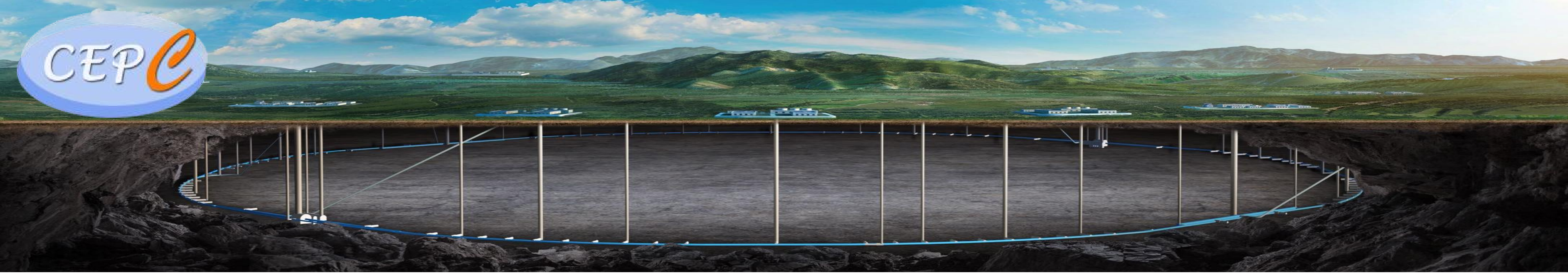

CEPC HCAL Detector

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- Introduction
- Requirements
- Technology survey and our choices
- Technical challenges
- R&D efforts and results
- Detailed design including electronics, cooling and mechanics
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- Research team and working plan
- Summary

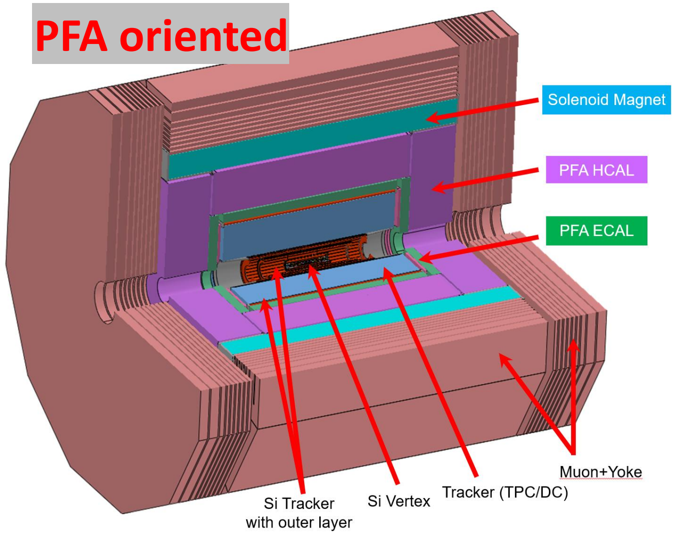
Introduction

- This talk is about the design and development of the CEPC Hadron calorimeter （HCAL）

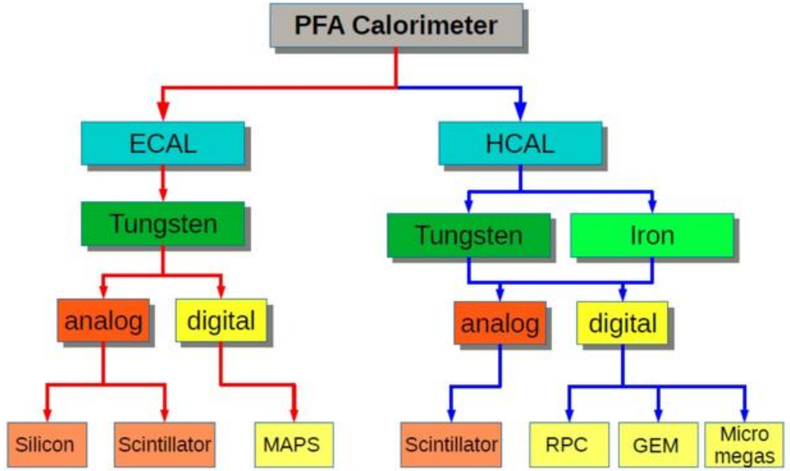
- HCAL have two options:
  - AHCAL
    - GS-AHCAL —>**Glass scintillator**
    - PS-AHCAL —>**Plastic scintillator**
  - SDHCAL base on RPC

The CEPC HCAL option

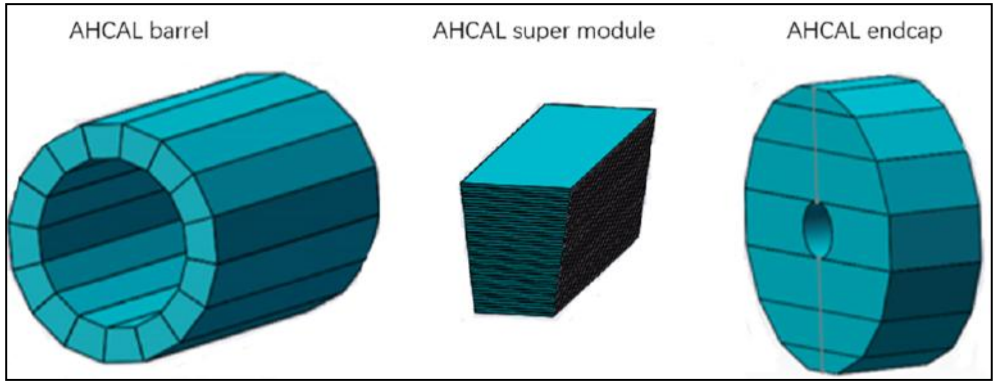
CEPC detector concept



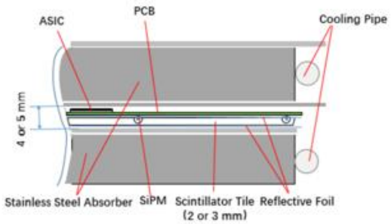
Landscape of PFA (or imaging) calorimeters



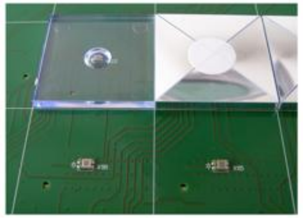
CEPC AHCAL Conceptual Design



Sandwich structure
Scintillator tile + Fe



SiPM on tile

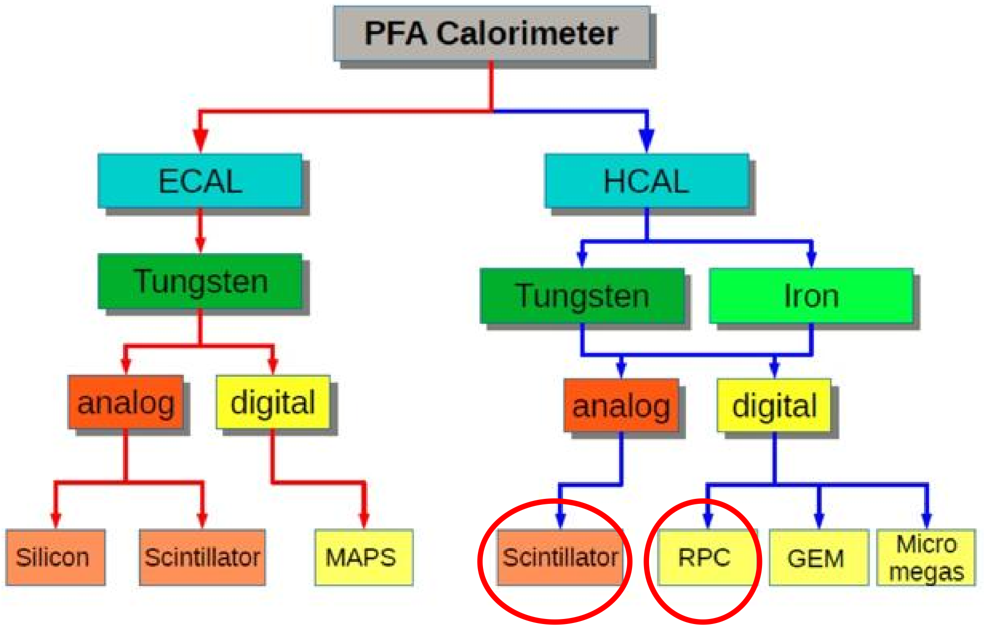


Requirement of CEPC HCAL

- HCAL: PFA calorimeter (High granularity calorimeter)
- Hardronic energy resolution: <60%/√E
- BMR requirements: 3~4% (H->gg)
- Nuclear interaction length: ≥6 λ_i
- Detection efficiency of scintillator cell for MIPS： >95%

Technology survey and our choices

- HCAL have three options: GS-AHCAL, PS-AHCAL and RPC-SDHCAL
- **AHCAL-GS:**
  - Scintillator cell size: **40×40×10 mm³**
  - GS cell response of MIP: ~80 p.e.
  - **BMR: ~3.4% （H->gg）**
- **AHCAL-PS:**
  - Scintillator cell size: **40×40×3 mm³**
  - **A 40 layers prototype was constructed and beam tested.**
  - Beam test results:
    - Energy resolution: $\frac{58.4\%}{\sqrt{E}} \oplus 1.7\%$
    - Energy linearity < 1.5%
  - **BMR: ~3.7% （H->gg）**
- **RPC-SDHCAL:**
  - Readout size： **10×10 mm² （Too much）**
  - Beamtest MIP detection efficiency： >96%
  - **BMR: ~3.6% （H->gg）**



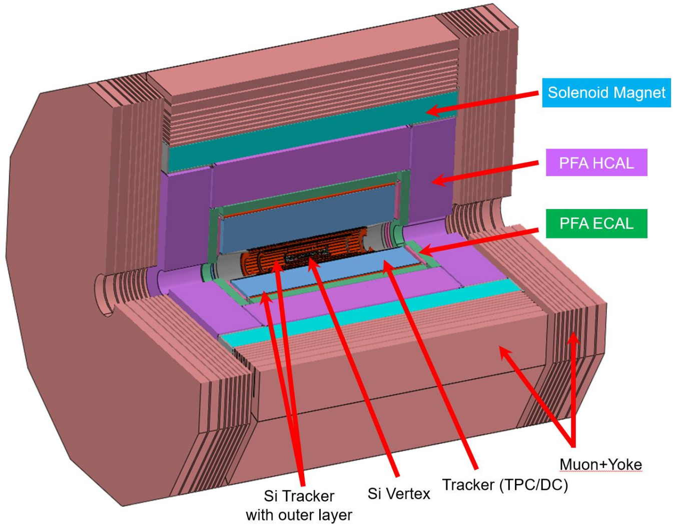
Main Technical Challenges

- The biggest challenge: **high granularity, 3D, large scale HCAL**
- Technical innovations created to meet the challenge
  - Technique for **large scale production of high quality scintillator tiles** in a low-cost way
  - Highly integrated, **fully embedded and scalable electronics** with a parallel readout design for high rate application
  - The **design and installation** of the **big size and heavy weight** detector structure.

GS-AHCAL proposed

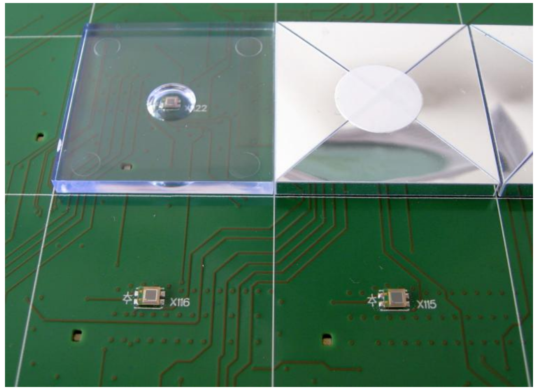
- PFA-oriented detector: the CEPC 4th conceptual design
  - Hadronic calorimeter (HCAL) with glass scintillator tiles
  - Requires glass scintillator: **dense, high light yield, low cost**
  - Expect to significantly **improve hadronic energy resolution**
    - **Aim at improving BMR 4% → 3%**

CEPC 4th detector concept



- R&D activities for glass scintillator HCAL
  - HCAL design, simulation studies and hardware developments
  - Glass scintillator tiles: testing with cosmics/sources/beams
    - Key requirement: MIP response ~100 p.e. in 10 mm thickness
  - PFA optimization and physics performance studies

"SiPM-on-Tile" design for AHCAL



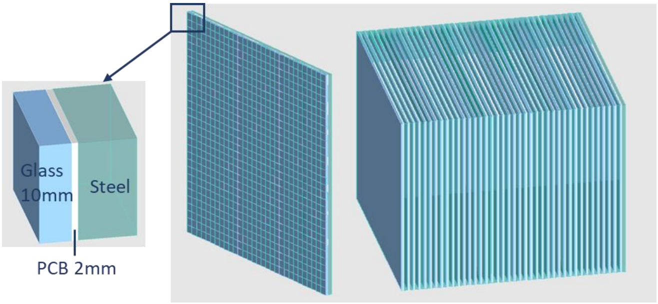
R&D

GS-AHCAL Simulation Studies and Beamtest

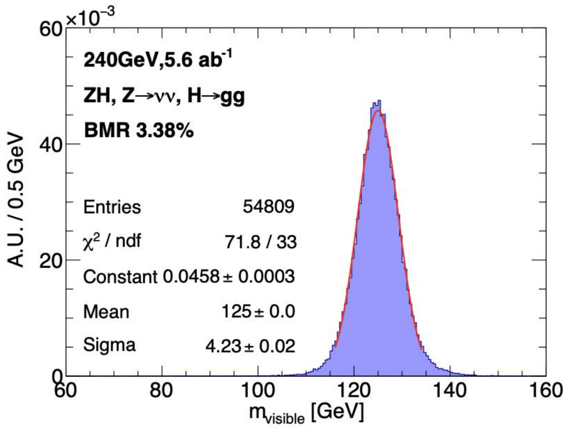
- **Geant4 simulation studies**
  - Geometry refer to Scint-Steel AHCAL: **Plastic scintillator->Glass scintillator**
  - Better energy resolution for hadrons
  - GS-AHCAL design optimizations:
    - **Density: 6 g/cm³**
    - **Thickness: 10 mm**
- **Beamtest of glass tiles**
  - MIP response:
    - **71-96 p.e./MIP in 40*40*10 cm³**
      → promising to achieve the goal
  - Readout by 6mm*6mm SiPM

Glass scintillator tiles

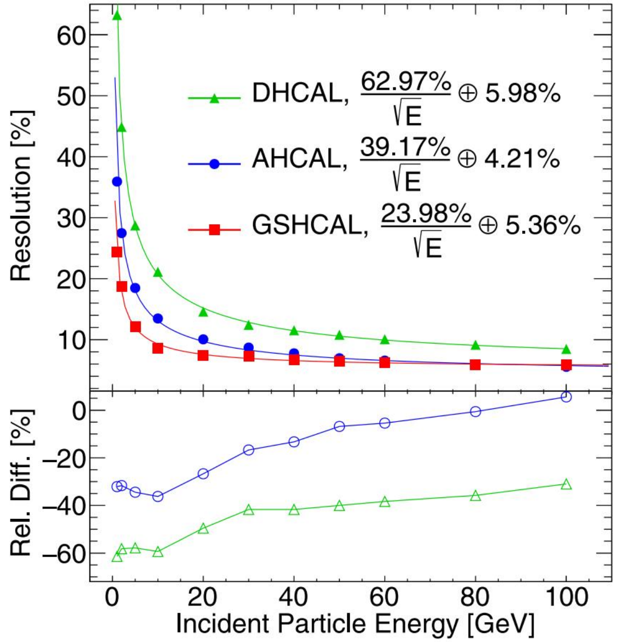
Glass scintillator HCAL



BMR result：3.38%



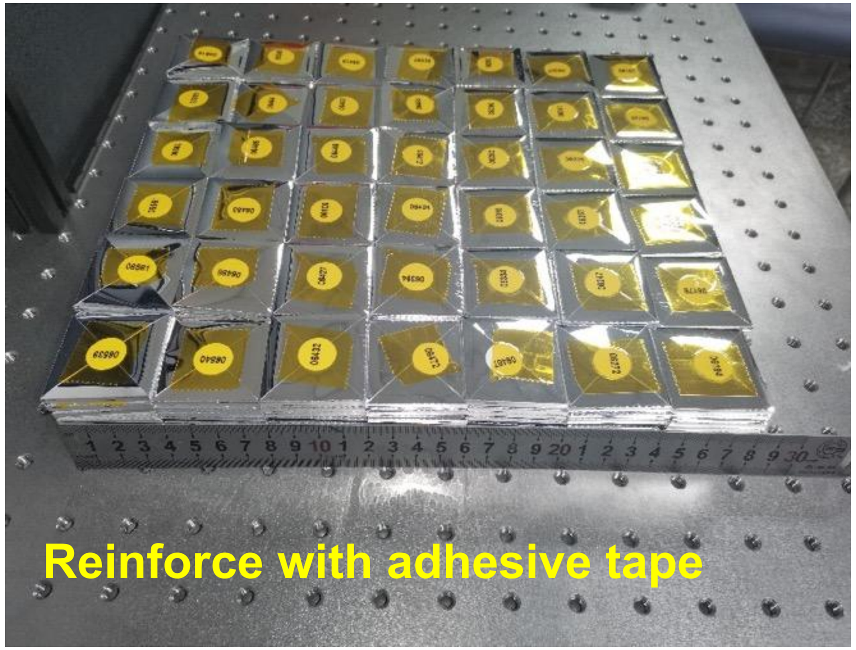
HCAL energy resolution



PS AHCAL tiles production and wrapping

- **Developed** an injection molding technique to produce large amounts of PS tiles in a cost-effective and efficient way

- **Developed** an automatic packaging machine to fast wrap scintillator tiles with ESR foils in large quantities.



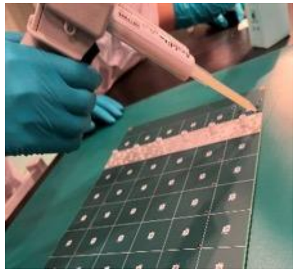
R&D

PS AHCAL prototype assembling

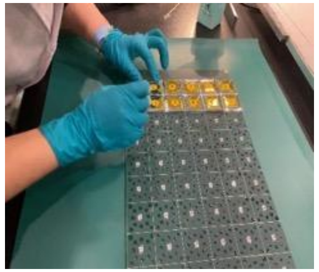
- Developed a procedure dedicated to fitting scintillator tiles onto the HBU boards

inspection

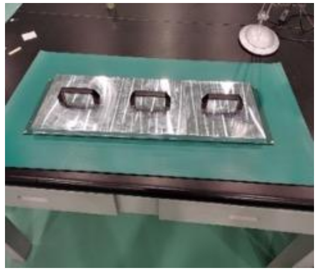
gluing



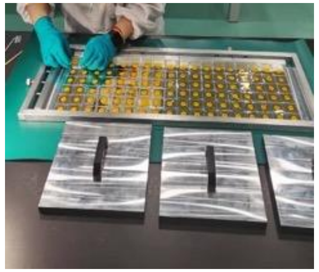
mounting

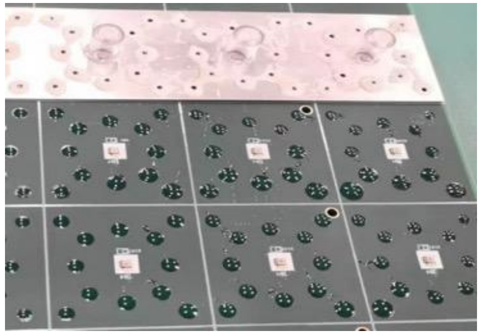


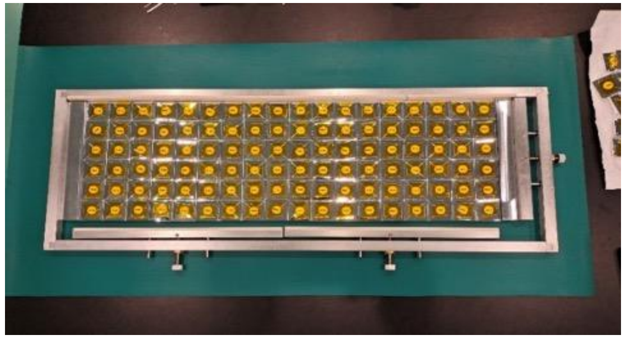
curing

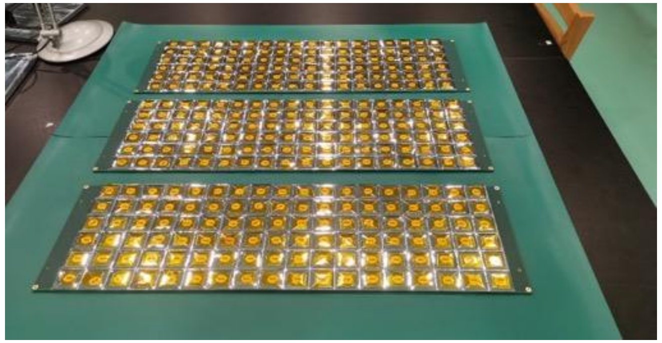


inspection

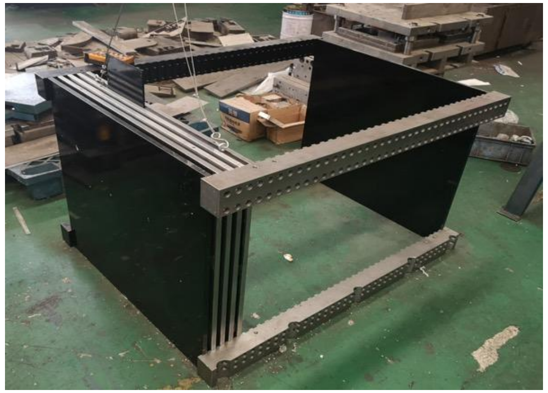








Absorber installation



Actvie layer installation

R&D

Beam tests at CERN

- $e^{\pm}$: 0.5-250 GeV/c
- $\pi^{\pm}$: 1-120 GeV/c
- High energy μ for calibration

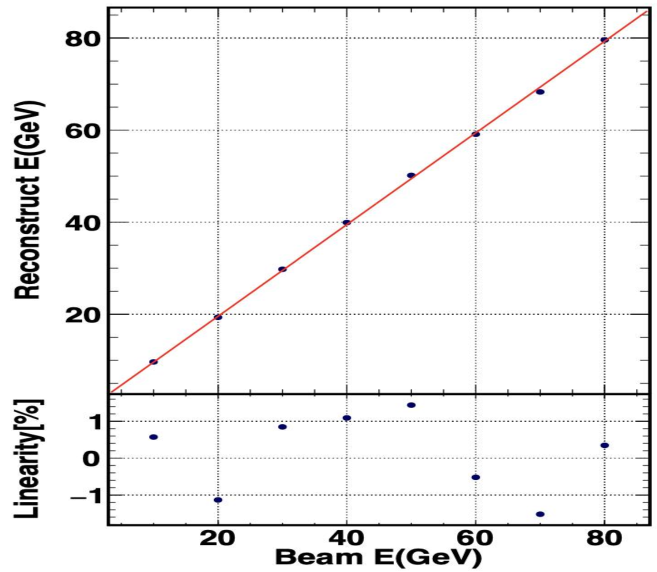
65 million events collected in total

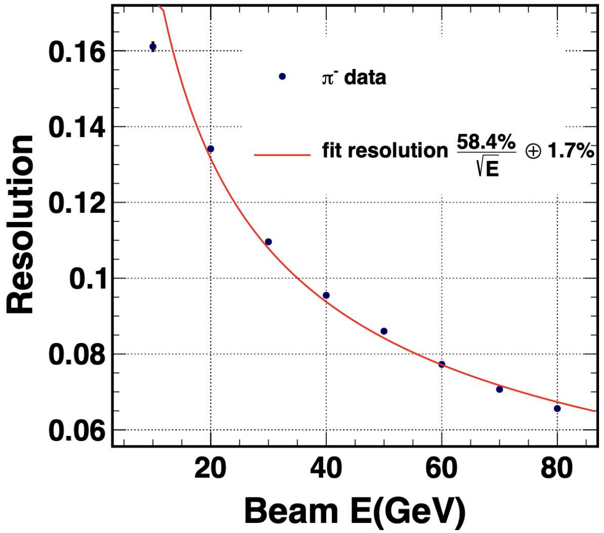
PS-AHCAL
Energy linearity and resolution for pions

R&D

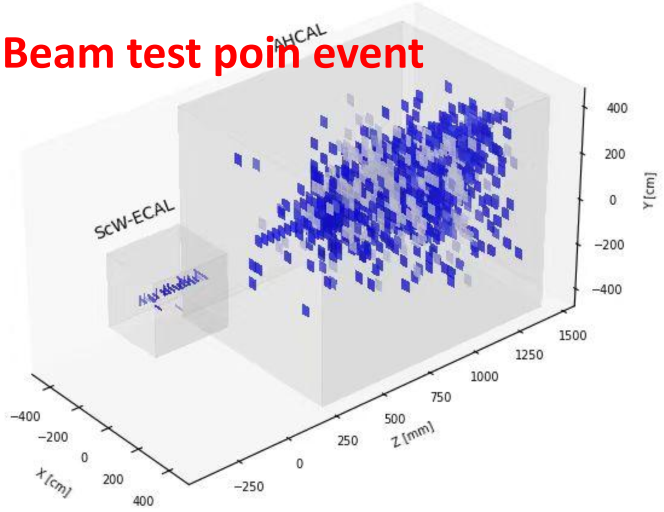
- Energy linearity: <1.5%
- Energy resolution is $\frac{58.4\%}{\sqrt{E}} \oplus 1.7\%$

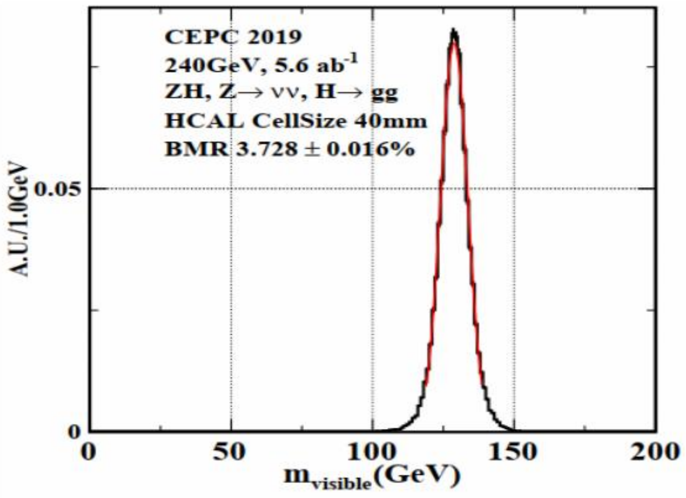
10 – 80 GeV





Beam test poin event

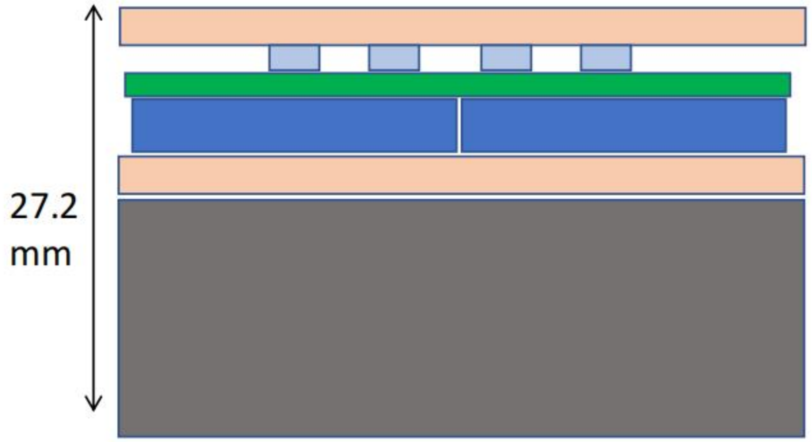




BMR Simulation result

Single layer structure of CEPC AHCAL

CEPC PS-AHCAL

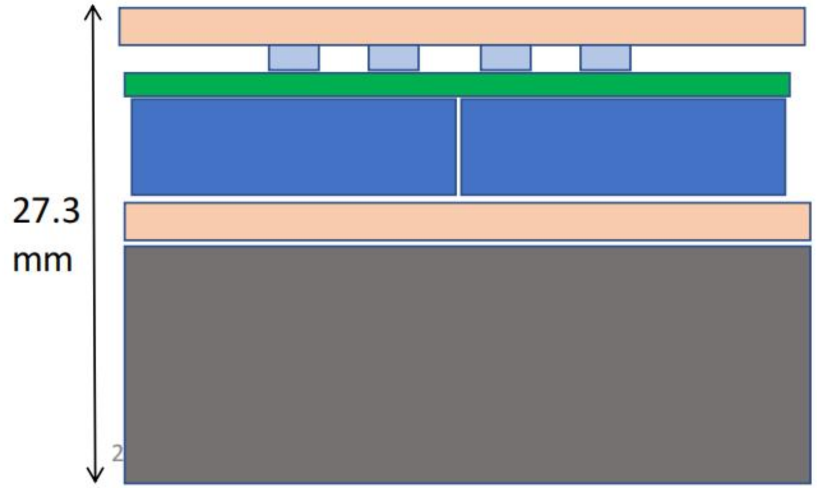


upper cover: 2mm SS
PCB+ ASIC ships:3.2mm
Scintillator cell:3.2mm
Bottom cober: 2mm

Absorber:16.8mm

48 layers
6.0 NIL
Total thickness:1305.6mm

CEPC GS-AHCAL



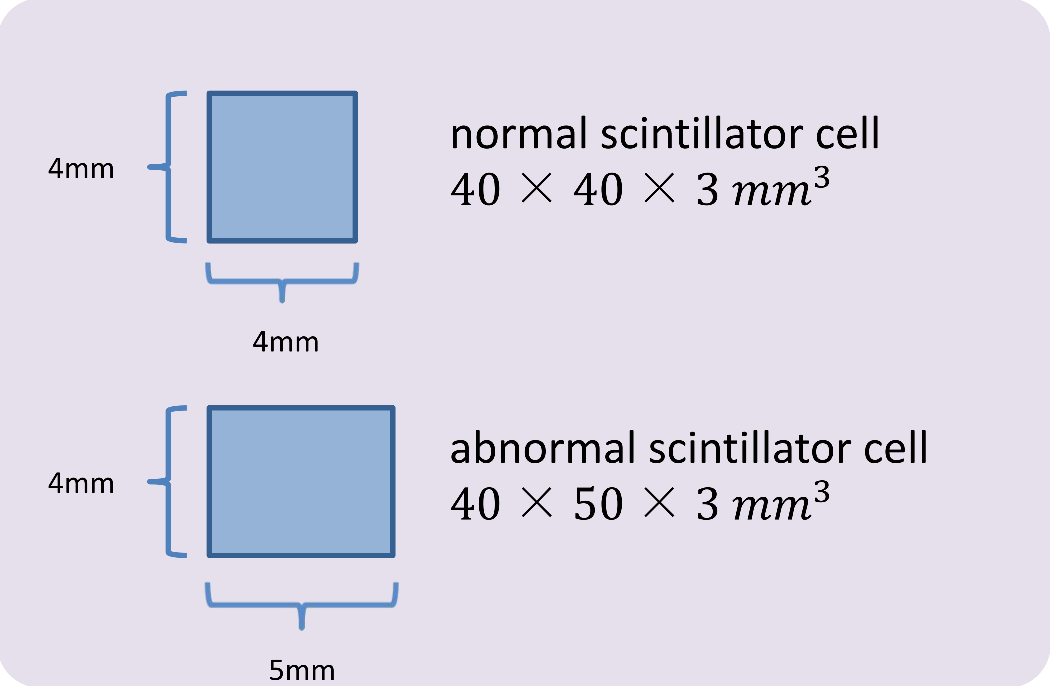
upper cover: 2mm SS
PCB+ ASIC ships:3.2mm
Scintillator cell:10.2mm
Bottom cober: 2mm

Absorber:9.9mm

48 layers
6.0 NIL
Total thickness:1310.4mm

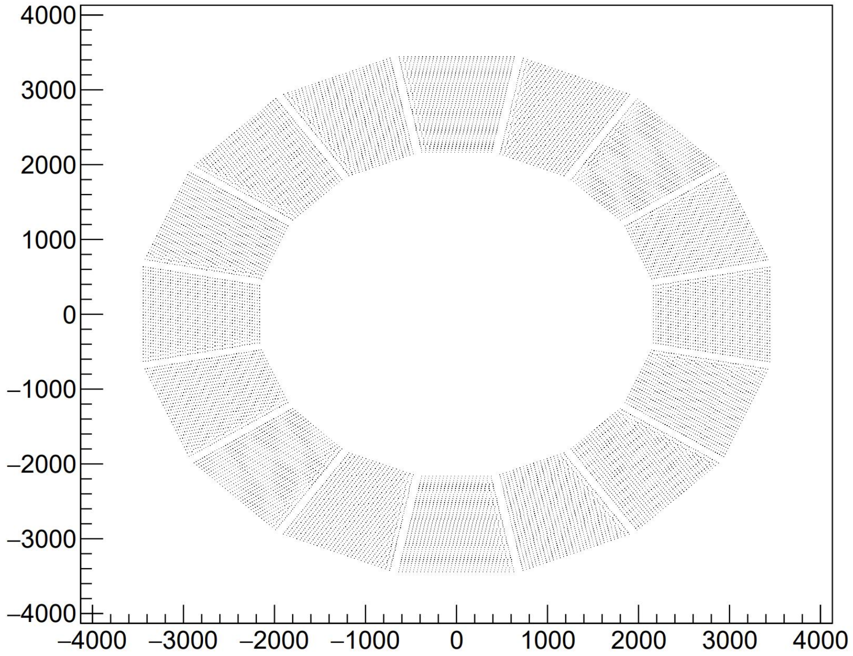
AHCAL Barrel Geometry design in CEPCSW

- In order to decrease dead area, **an odd size scintillator** has been introduced



Dead area: 0.75% caused by uninstrumented region
1.4% caused by gap between scintllators
4.5% cause by supporting structure

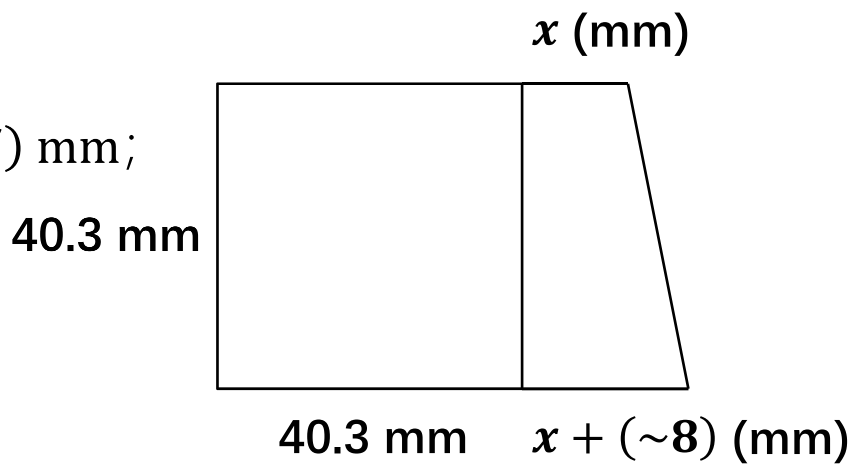
AHCAL Barrel can initially work in CEPCSW



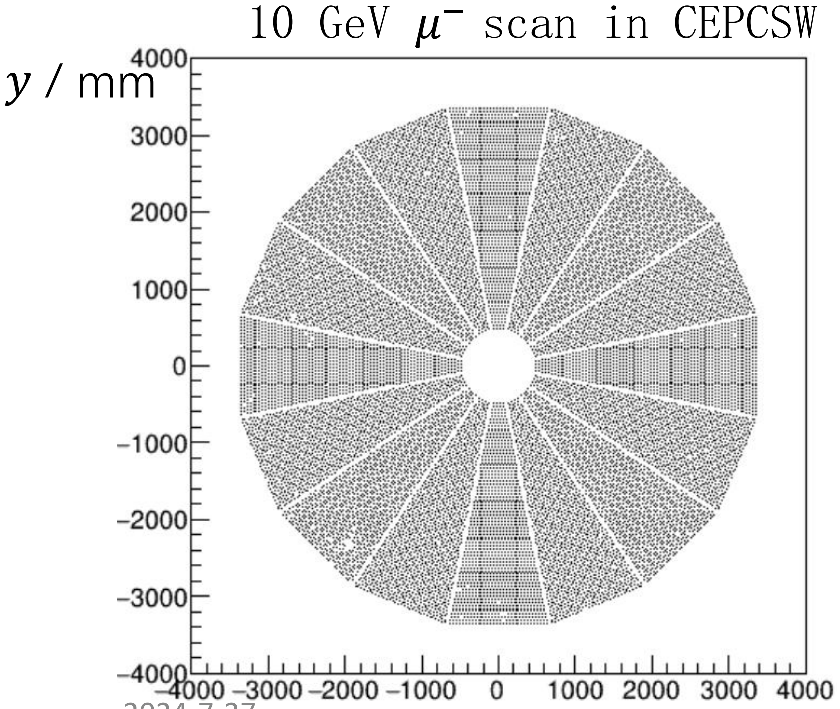
Hitmap in xy plane using muon scan

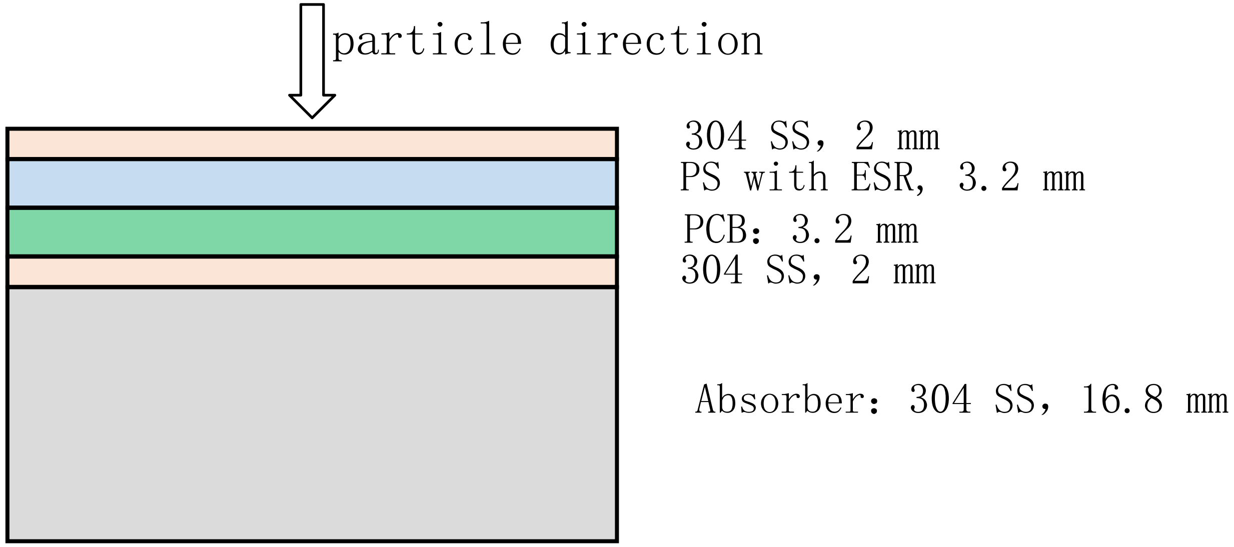
AHCAL Endcap Geometry design in CEPCSW

- **Cell basic size：** $40.3 \times 40.3 \times 27.2\ \text{mm}^3$
- **Odd shape scintillator：** 5 types, shorter edge $x = (0,\ 4.5,\ 9,\ 14,\ 17)$ mm; longer edge： $x + 8$ mm
- **Dead area：0.54%**

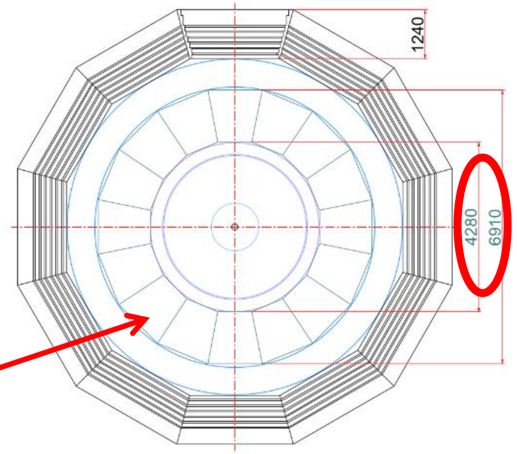


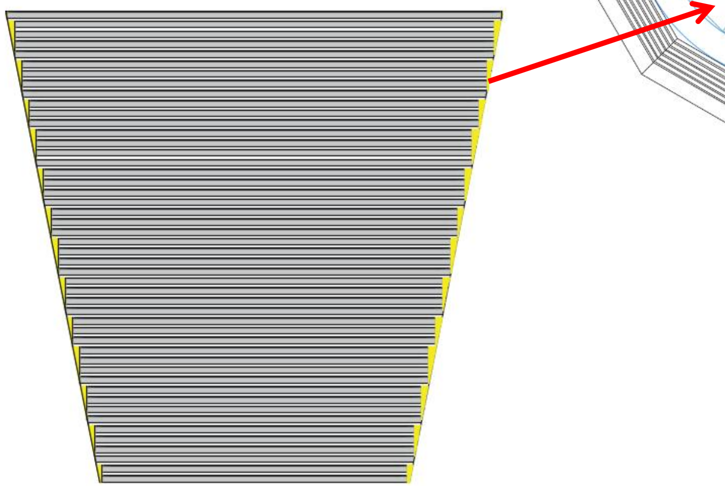
AHCAL Barrel can initially work in CEPCSW





Barrel HCAL requirements for mechanical design





1/16 section

- **Totally 48 layers**
- **Thickness: 1315mm**
- **Thickness of each layer: 27.4mm**

Requirement for layout

- Totally 16 equal divisions
- Distance between two symmetry outer edges is 6910mm
- Distance between two symmetry inner edges is 4280mm
- Total length： 6460mm

Requirement for physics

- The dead zone area： **≤1%**

Requirement for mechanics

- Stiffness: Each layer deformation is **< 0.5mm** (including manufacturing tolerance, installation tolerance, self gravity)
- Strength: The stress is lower than material allowable stress

Barrel HCAL preliminary mechanical design

Based on PS-AHCAL

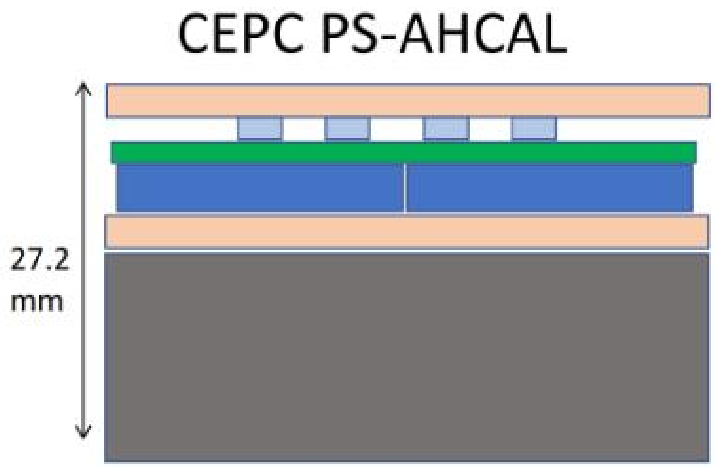
- Cell size： 4cm×4cm×3mm

Channel number

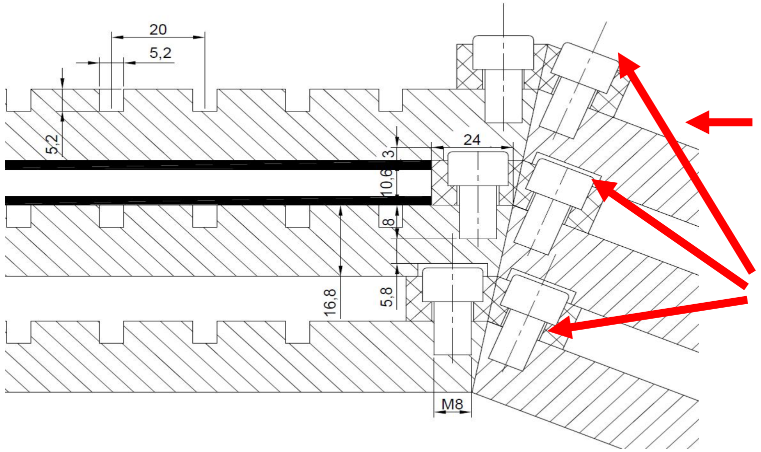
- Channels for 1/16 section : **211.2 k**
- Total channels: **3.38 M**

Weight

- Weight of 1/16 section: **59.4 tons**
- Total weight: **951 tons**

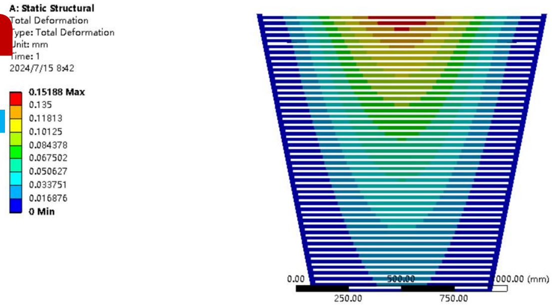


Barrel HCAL preliminary mechanical design



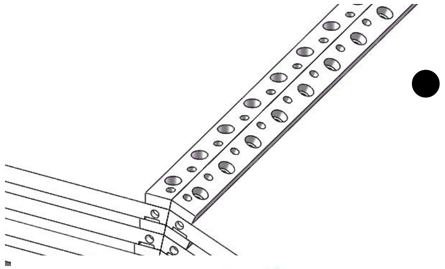
Absorption plate

Trapezoid plate

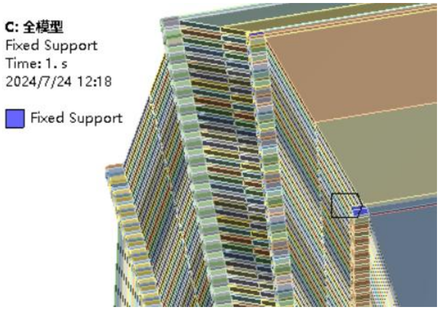


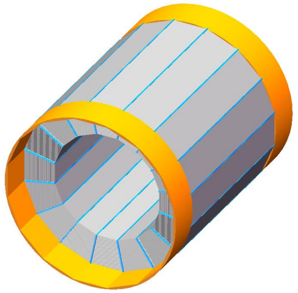
One section assembling condition under gravity

- Max. stress: 4.6 MPa. Max. deformation: 0.15mm

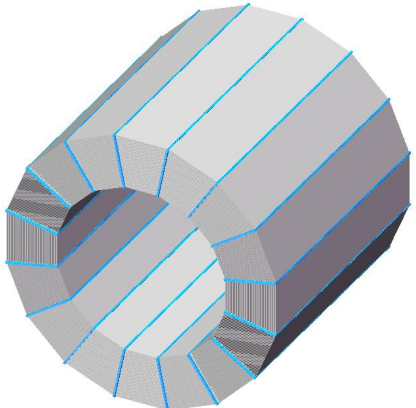


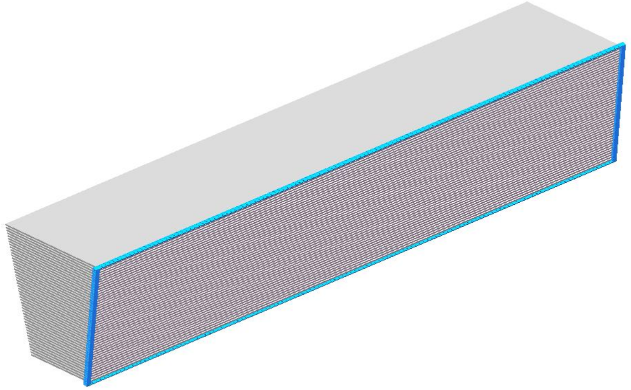
- One trapezoid plate connects with the upper and lower absorption layer by bolts

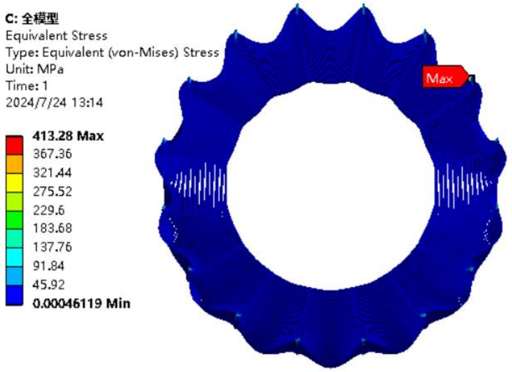


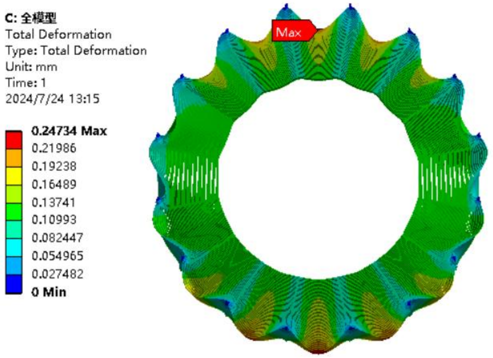


General model: Fix support applied on the top surface of each end





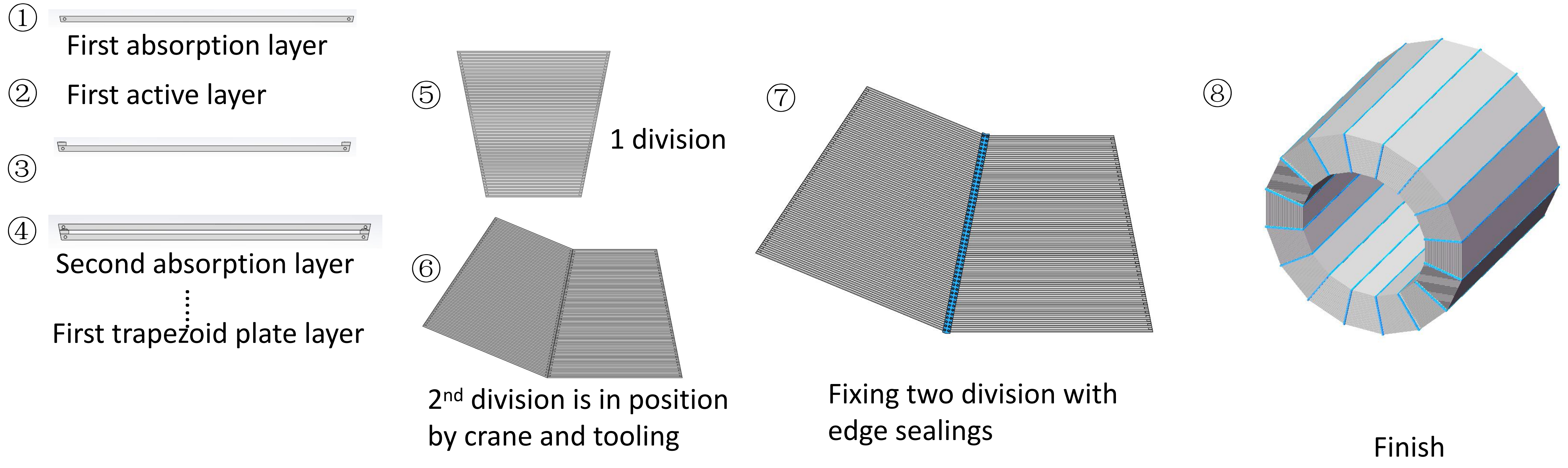




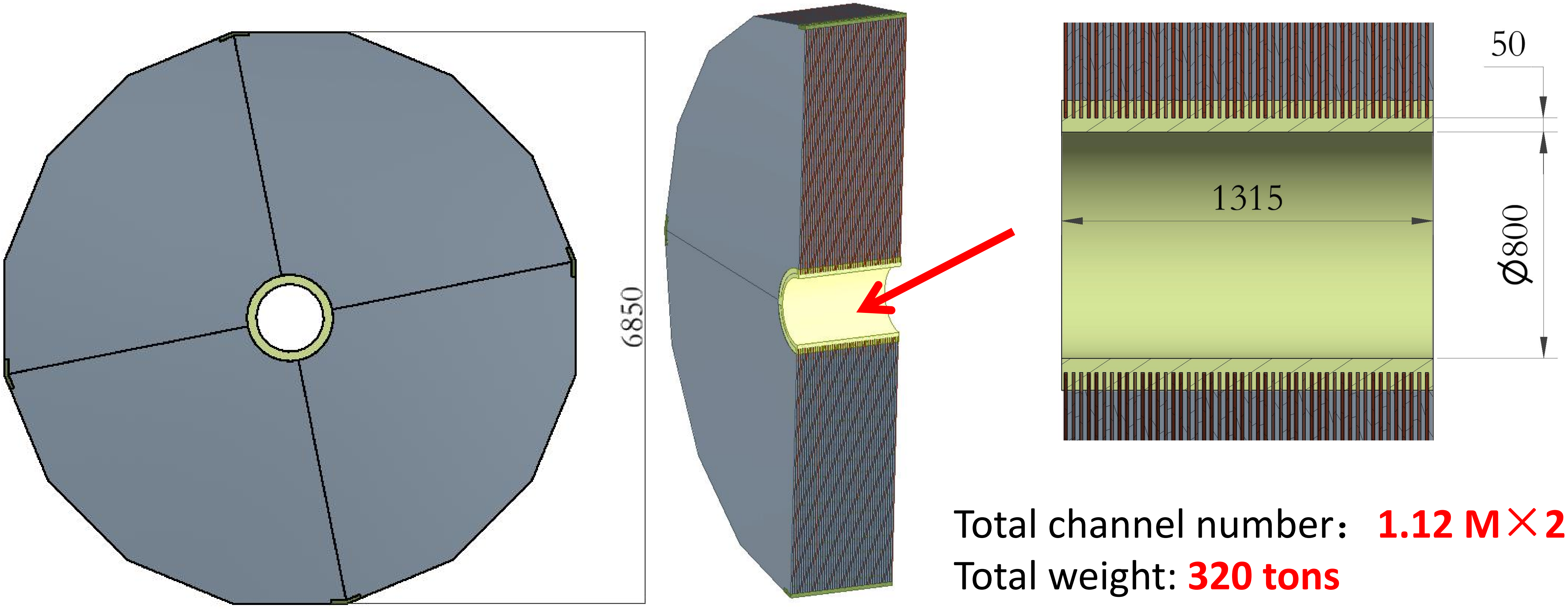
Gravity condition

- Each two divisions are connected by 4 edge sealings
- Max. stress: 413.3MPa. Max. deformation: 0.25mm

Mechanic installation scheme



HCAL endcap mechanic preliminary design



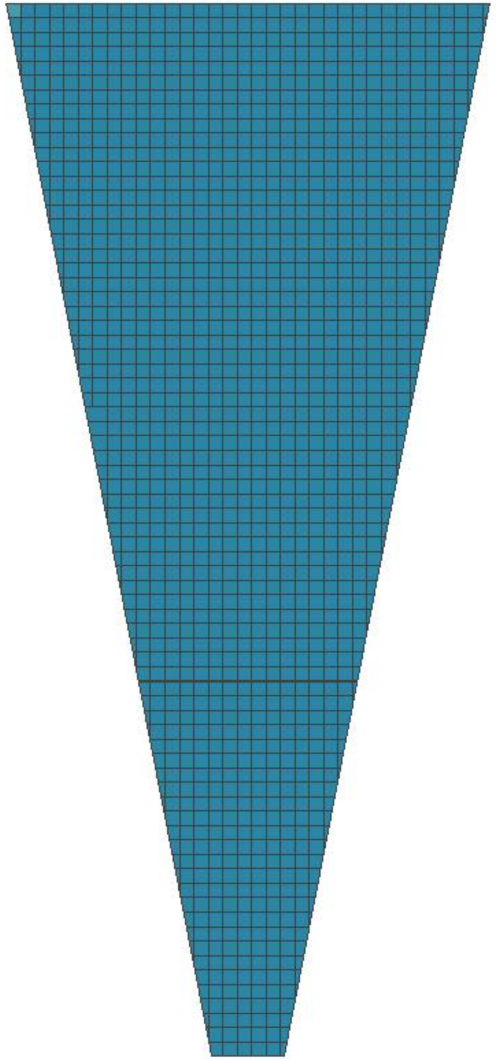
Total channel number： **1.12 M×2**

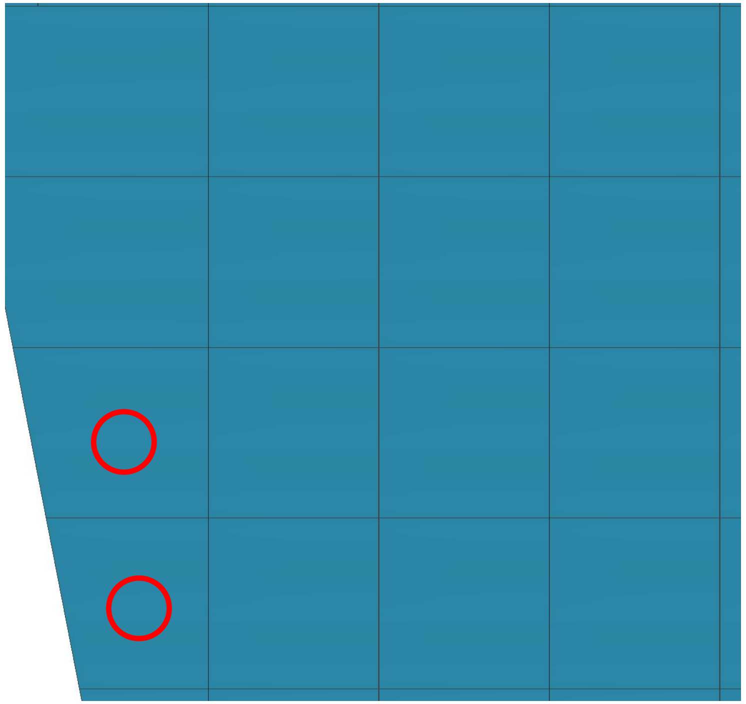
Total weight: **320 tons**

The active layer: **16 sections**

The center support drum: **50mm thick**

HCAL endcap scintillator preliminary arrangement





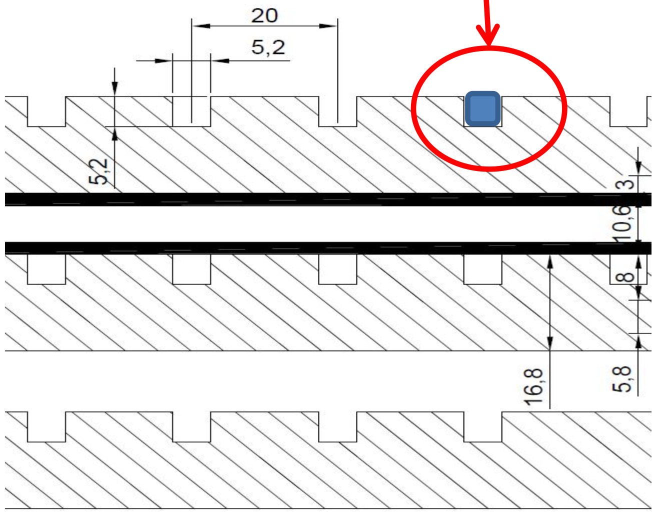
- 1/16 session : 73 Line scintillator
- The basic size of scintillator 40mm×40mm×3mm
- At the edge, the trapezoidal scintillator is used.
- The dead area: <1%

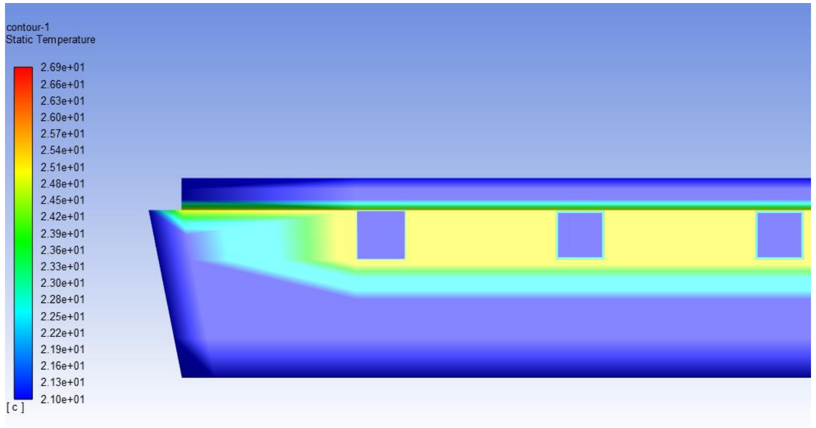
Barrel HCAL preliminary cooling design

Requirement for cooling

- Heat power: **15mW/channel**
- Temperature difference within one channel: **±0.1℃**
- Temperature difference between different channels: **±1.5℃**

Cooling pipe

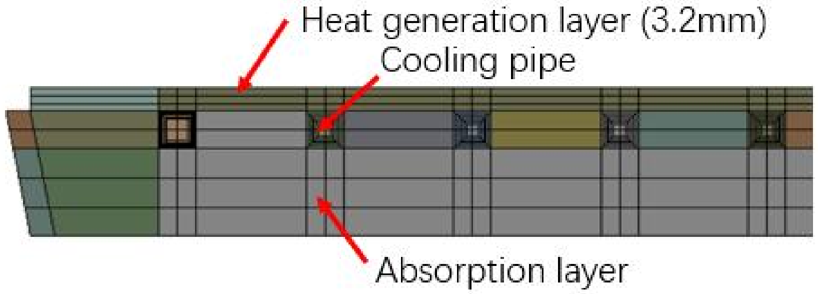




Temperature distribution along thickness direction

Fluid flow (fluent) simulation

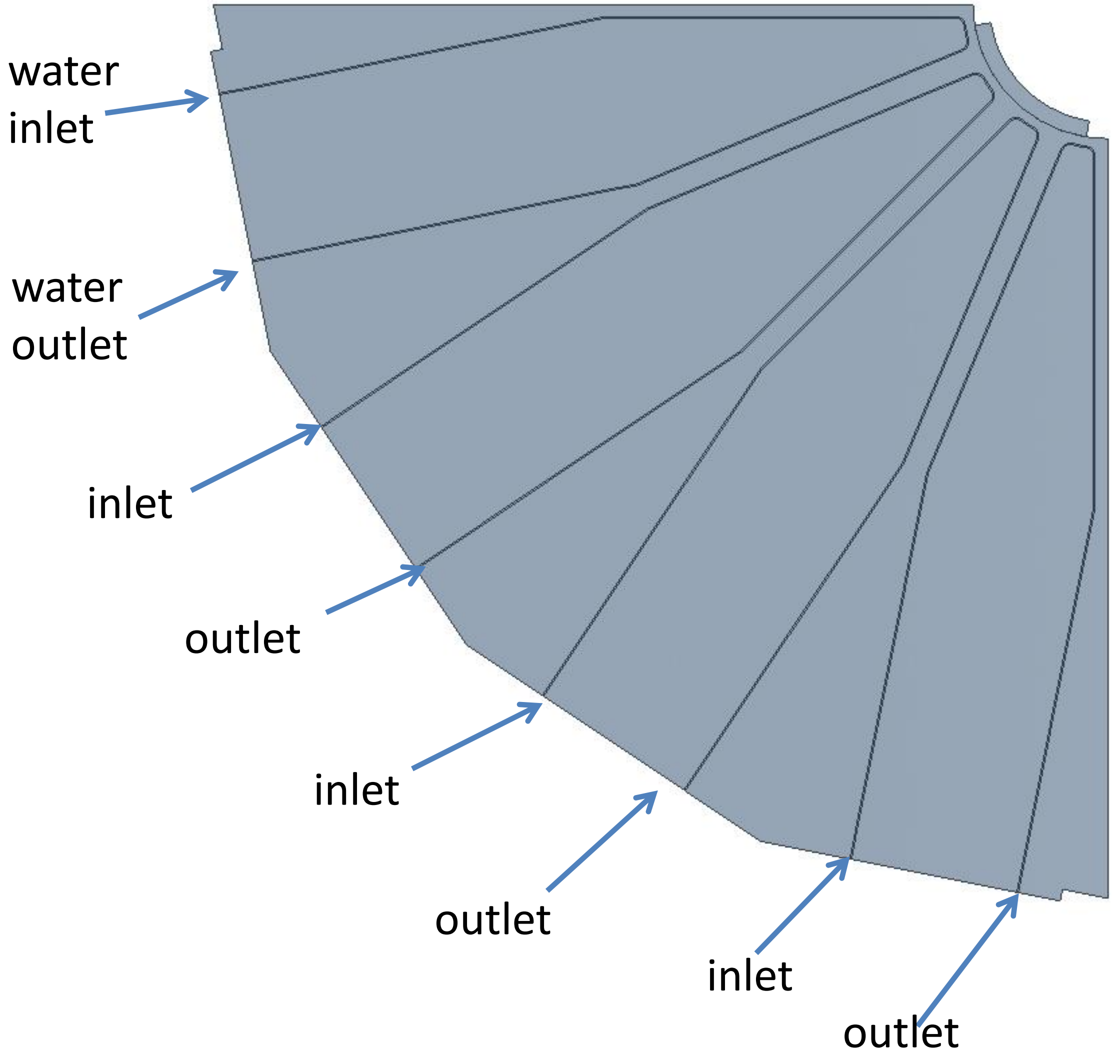
- Water inlet temperature: 21℃
- Surrounding temperature:25℃



Model

- Max. temperature: **25.58℃**
- Model including absorption layer, cooling pipe, cover plate, PCB, PS, chip
- Both inlet and outlet are 21℃

HCAL endcap preliminary cooling design

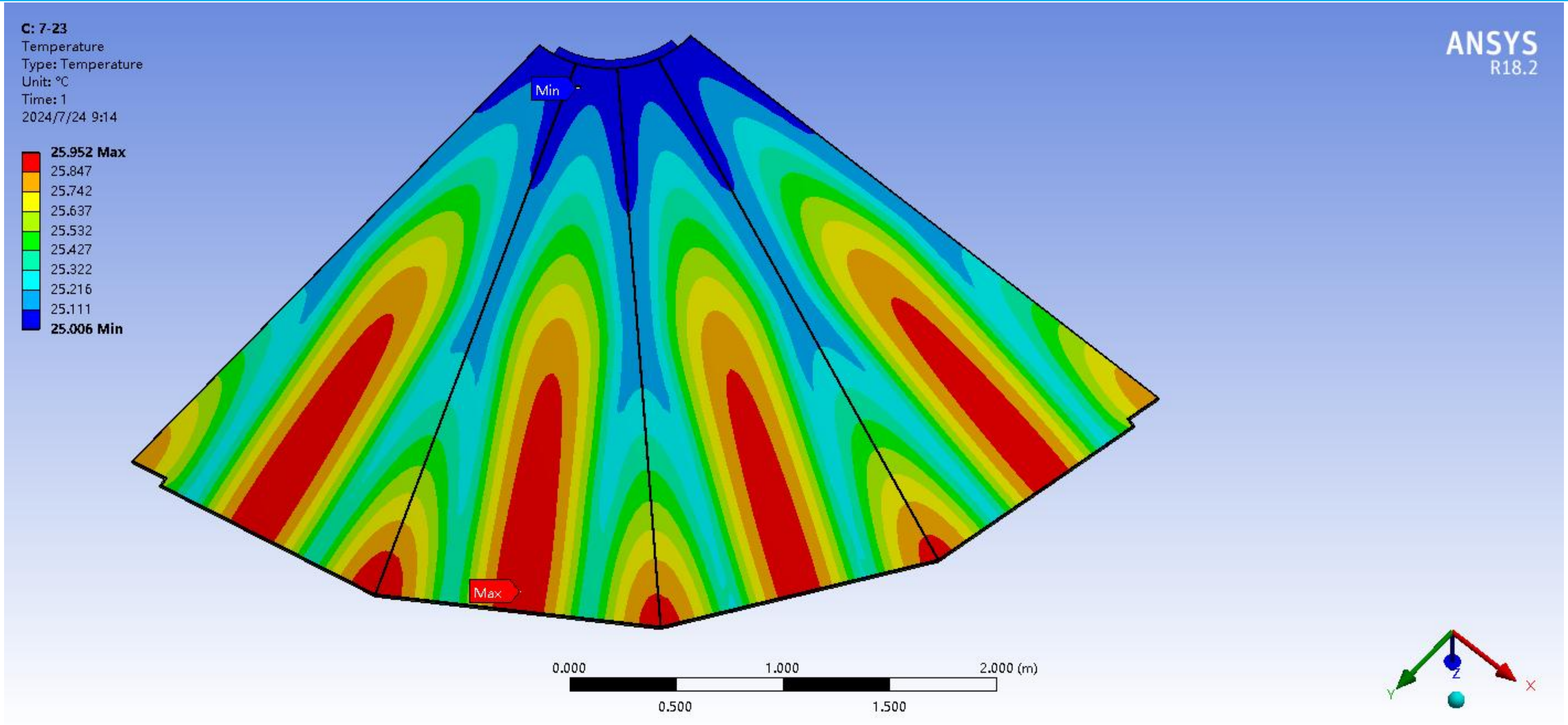


- Diameter of cooling Pipe： 5mm
- Each 1/16 session has one cooling pipe .
- The cooling effect is simulated for 1/4 detection area.

Heat source: **15mw/ch**

Water temperature: **25 °C**

HCAL endcap cooling calculation

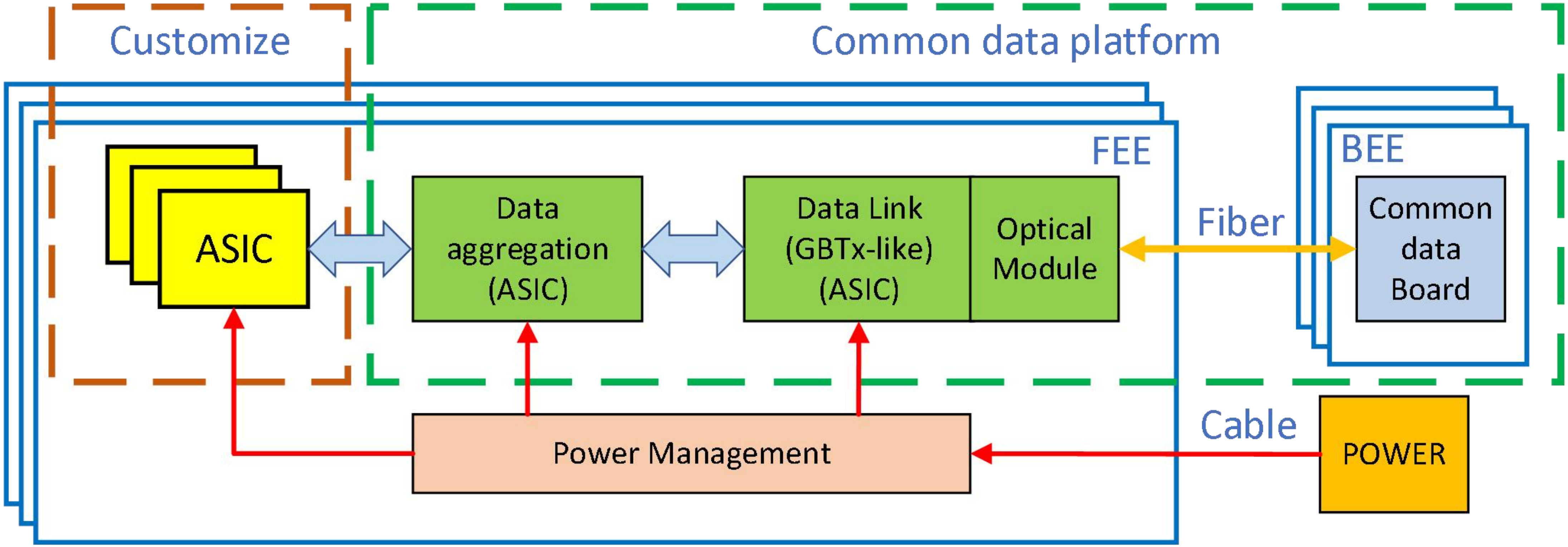


Water temperature： **25 °C**

Temperature range： **25 °C<T<26 °C**

Temperature rise： <1 °C

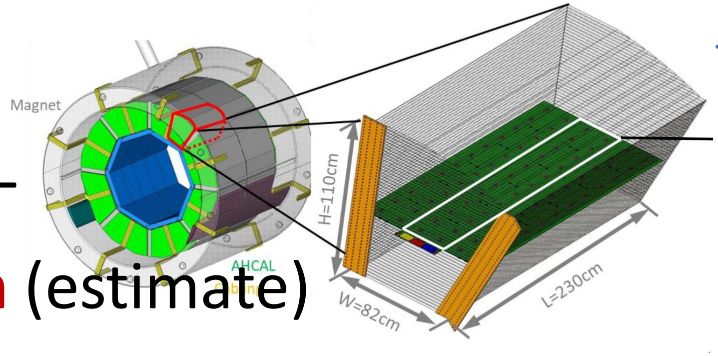
Electronics diagram for HCAL

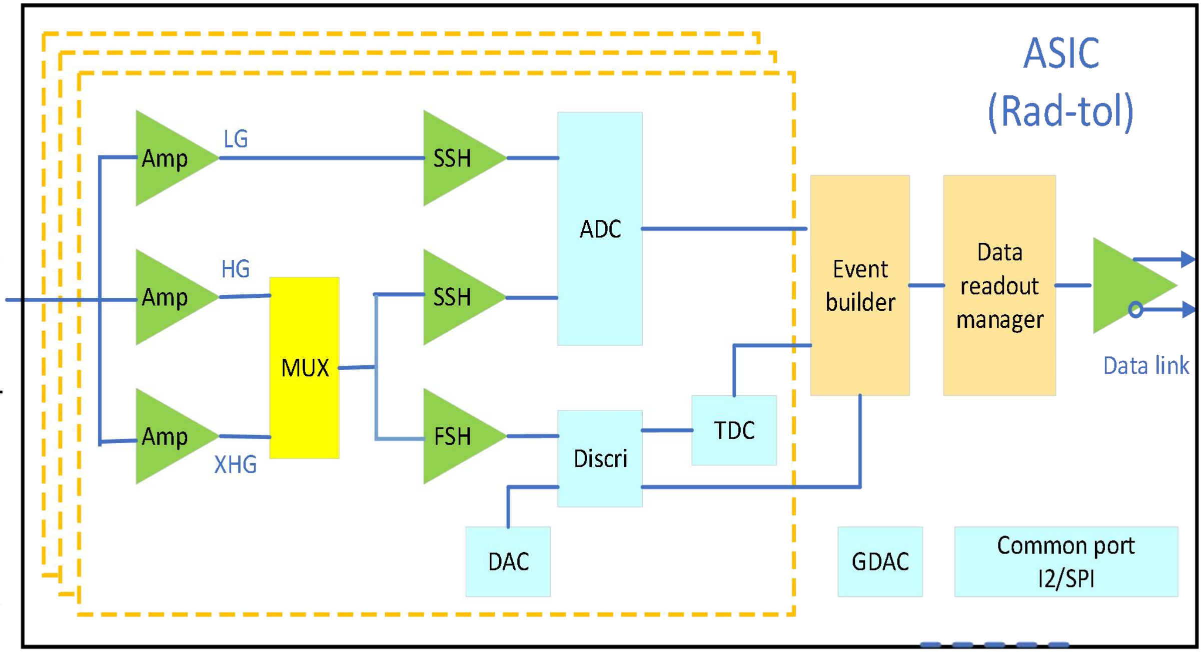


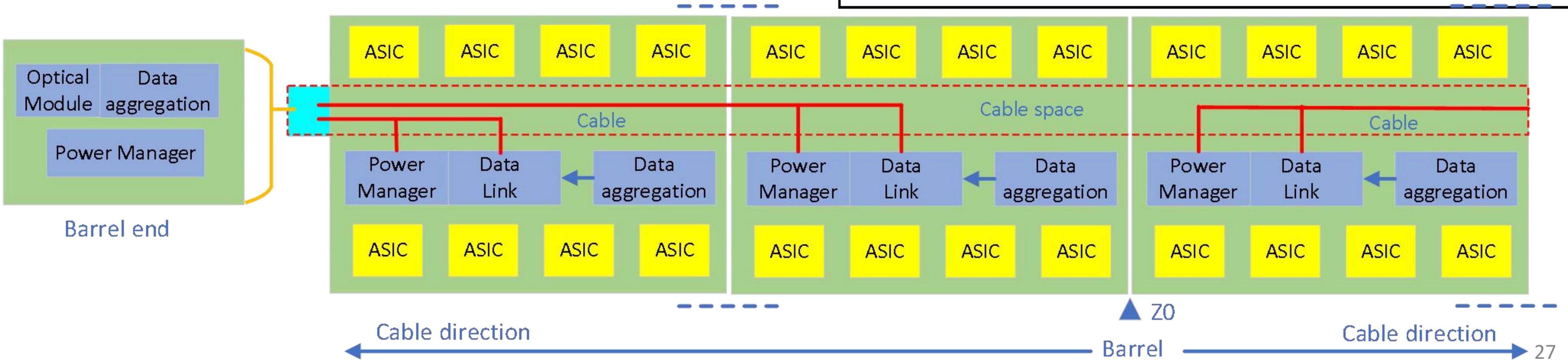
- Energy Measurement: ASIC for ECAL & HCAL
- Data transmission: common data platform （see electronics report）
- Trigger mode: FEE triggerless readout

Readout electronics for HCAL

- Thickness : 3mm (PCB 1mm, Chip 2mm)
- Aggregation board at the end of barrel, cable connection
- ASIC: same as ECAL
- Power： **15mW/ch** (estimate)







AHCAL Research Team

Detector:

Staff(10): Jianbei Liu, Haijun Yang, Yong Liu, Shen Qian, Yunlong Zhang, Shu Li, Boxiang Yu, Hao Liu, Jiechen Jiang, Jiaxuan Wang

Student(5): Dejing Du, Siyuan Song, Jiyuan Chen, Hongbin Diao, Yanyun Duan

Electronics:

Staff(5):Wei Wei, Jinfan Chang, XiongBo Yan, Anshun Zhou, Zhongtao Shen,

Mechanics:

Staff(3):Quan Ji, Yatian Pei, Junsong Zhang

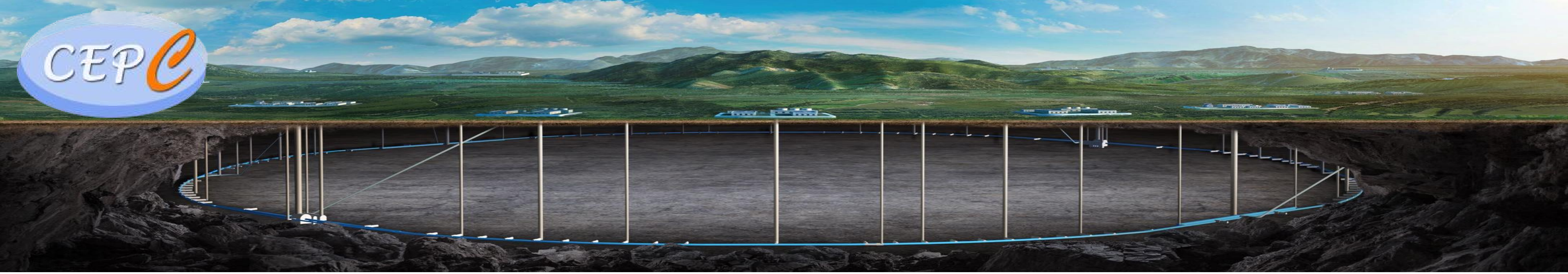
Institution: USTC, SJTU, IHEP

Working plan

- **Detector**
  - R&D of glass scintillator
  - Test odd shape plastic scintillator
- **Electronics**
  - AISC chips R&D
  - Compeleteing electronics design
- **Mechanic**
  - Optimization of the mechanic design.
  - Optimization of the cooling design.
- **Simulation**
  - Optimization AHCAL geometric settings in CEPCSW .
  - AHCAL full simulation under CEPCSW

Summary

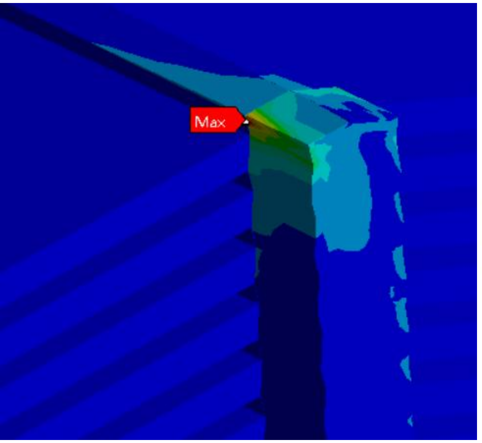
- **Detector**
  - GS of GS-AHCAL was develped and tested, GS-AHCAL was simulated.
  - PS-AHCAL prototype has been constructed and beam tested.
- **Mechanic**
  - The preliminary design of AHCAL mechanic include barrel and endcap has been completed.
  - The preliminary design of the cooling has been completed.
- **Simulation**
  - AHCAL geometric settings in CEPCSW is ready.
  - AHCAL full simulation in CEPCSW will been soon.

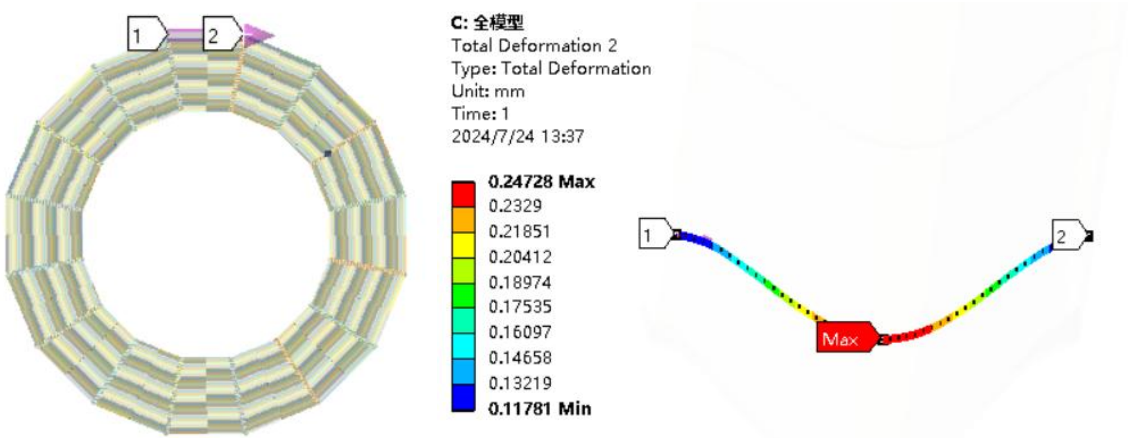


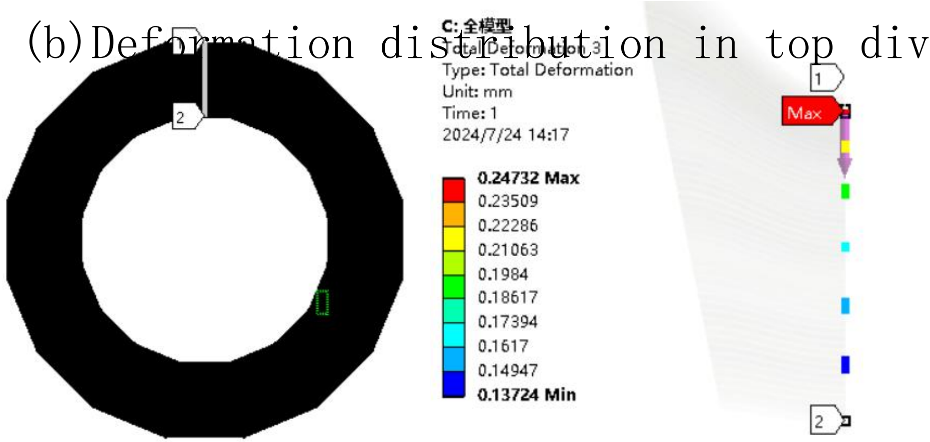
Thank you for your attention!

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

Backup





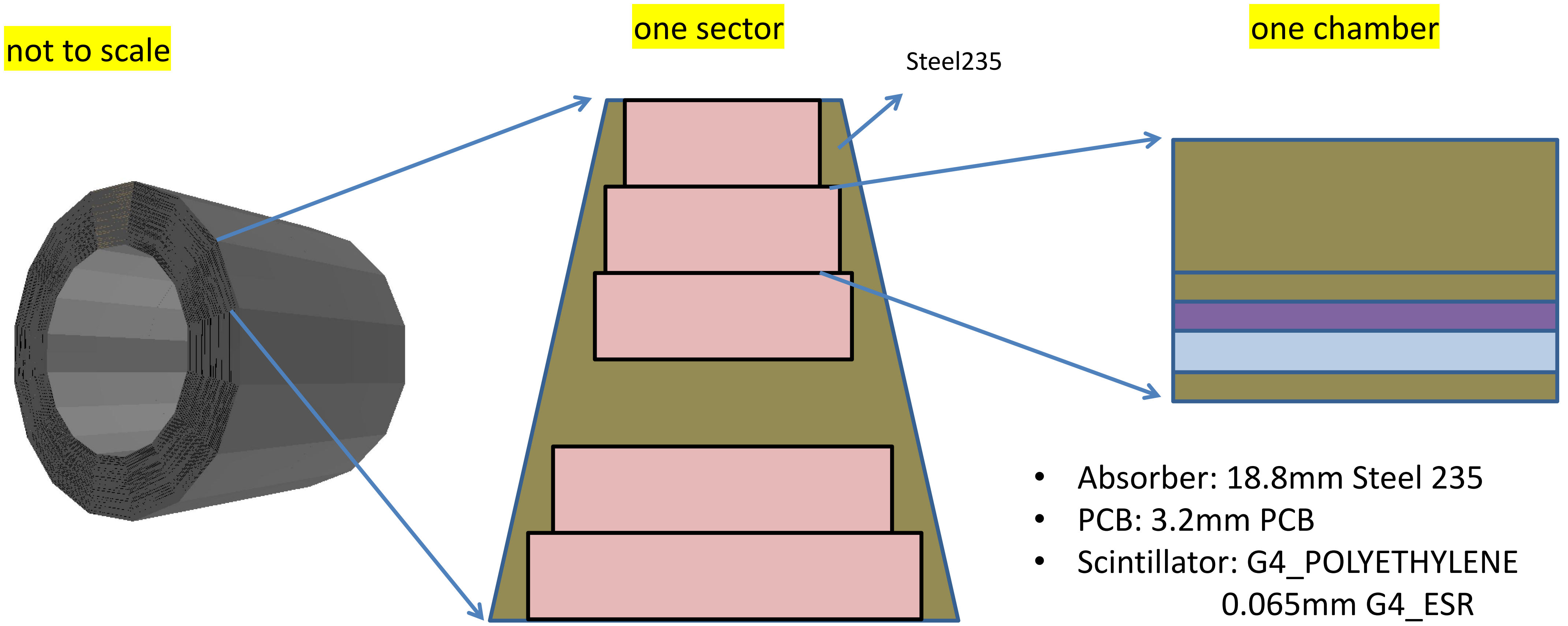


(b)Deformation distribution in top div

Max. stress position (a)Deformation distribution in top absorption layer

- Max. stress occurred at the transition zone of edge sealings between fix support and no support. (Solving it by changing this zone by high strength steel or changing the structure of this zone)
- Relative deformation: 0.13mm of (a) and 0.11mm of(b)
- Deformation of V2 is smaller than V1, installation scheme of V2 is easier than V1

CEPCSW AHCAL Barrel Geometry

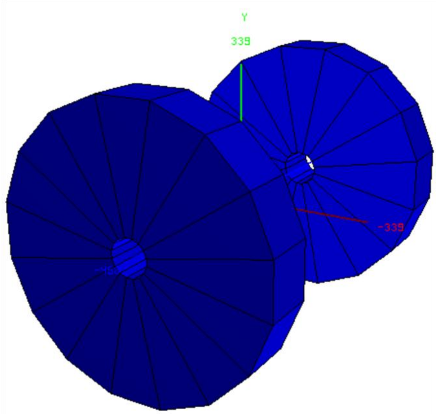


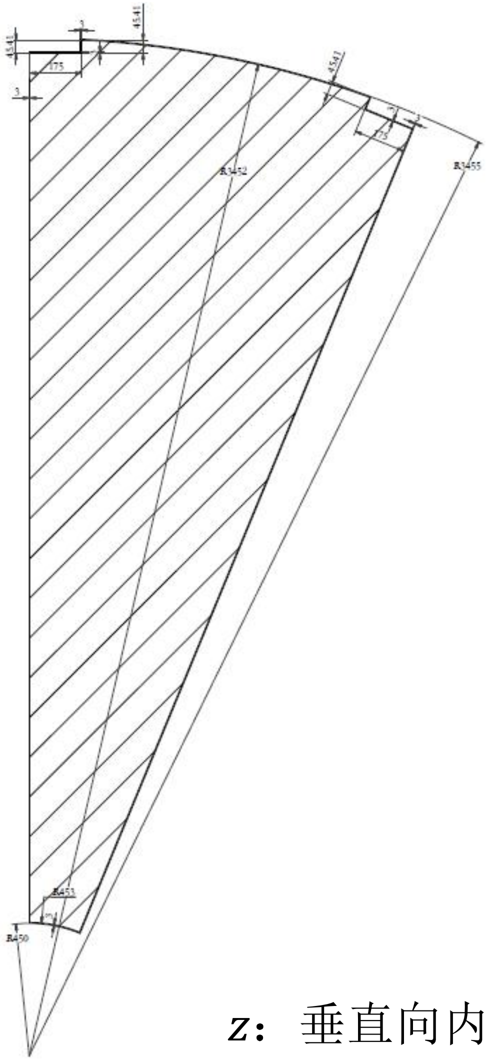
- Absorber: 18.8mm Steel 235
- PCB: 3.2mm PCB
- Scintillator: G4_POLYETHYLENE
  0.065mm G4_ESR
  - total distance in xy plane: 40.3mm
  - total thickness: 3.2mm
- Absorber: 2mm Steel235

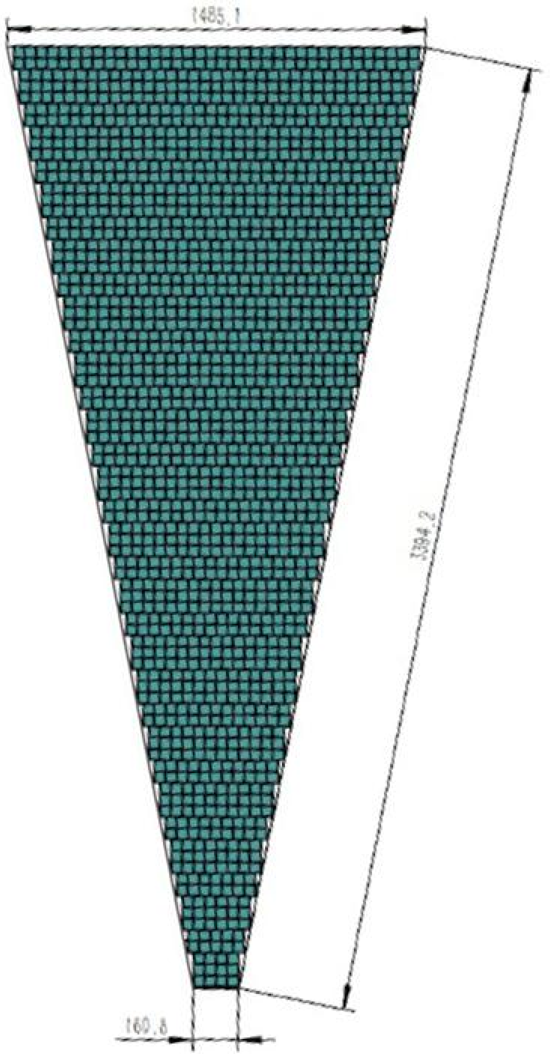
HCAL Endcap Set in CEPCSW

From Jiyuan

- Active layer： 16 trapezoidal modules constitute a regular hexadecagon
- Absorber： 4 fan-shaped areas constitute the circular ring,
- Size：
  - Inner radius： 400 mm
  - Outter radius ： 3455 mm
  - Thickness： 1315 mm
  - Radius of Inner Support Ring： 450 mm
  - Scintillator thickness： 3 mm





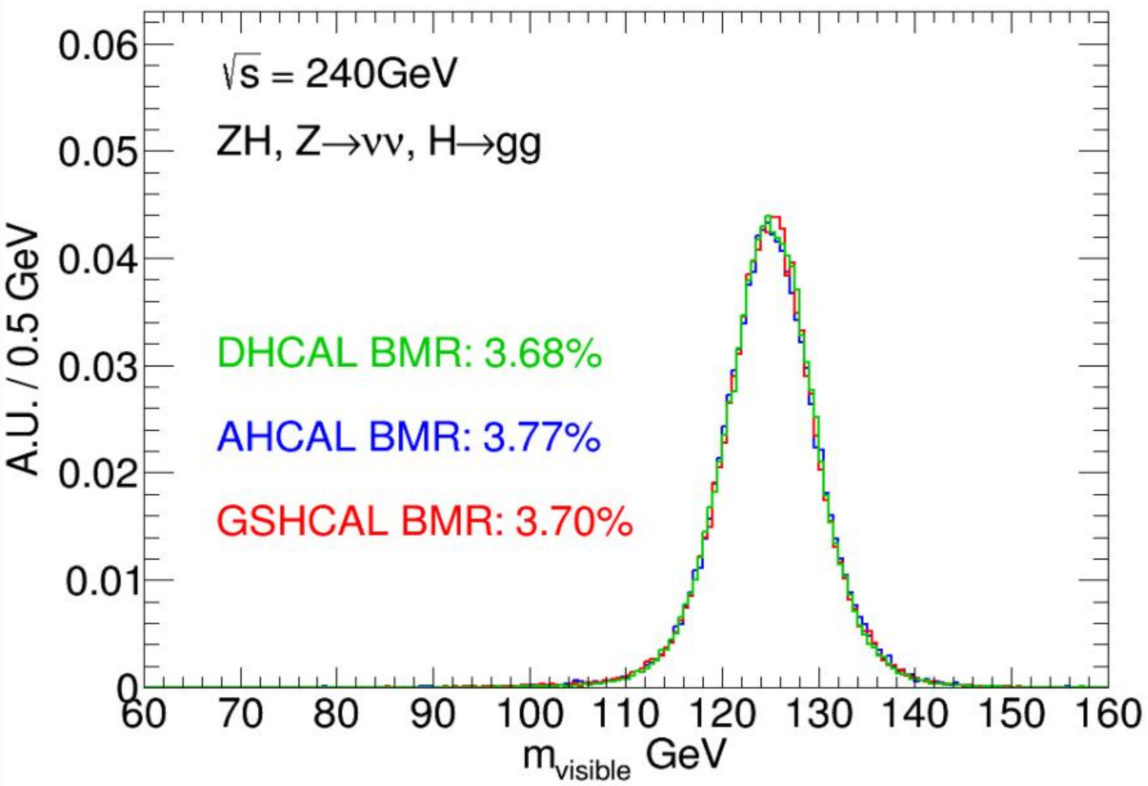


z：垂直向内

（仅显示 16 边形灵敏区）

2.4 GSHCAL vs. Baseline Design

Parameter	GSHCAL	AHCAL	DHCAL
Readout	Analog	Analog	Digital
Number of layers	40	40	40
Layer thickness	0.125 lambda (3mm GS +18.8mm Steel)	0.125 lambda (3mm PS +20mm Steel)	0.12 lambda (3mm RPC +20mm Steel
Total Nuclear Interaction Length	5 lambda	5 lambda	4.8 lambda
Transverse Cell Size	40x40 mm^2	40x40 mm^2	**10x10 mm^2**
Sensitive Material Density	6 g/cm^3	1 g/cm^3	< 10^{-3} g/cm^3
HCAL Thickness	**873 mm**	931 mm	931 mm
HCAL Volume	**13 m^3(GS) 81 m^3(Steel)**	14 m^3(PS) 91 m^3(Steel)	14 m^3(RPC) 91 m^3(Steel)
Number of Cells	**2.7×10^6**	2.8×10^6	4.5×10^7



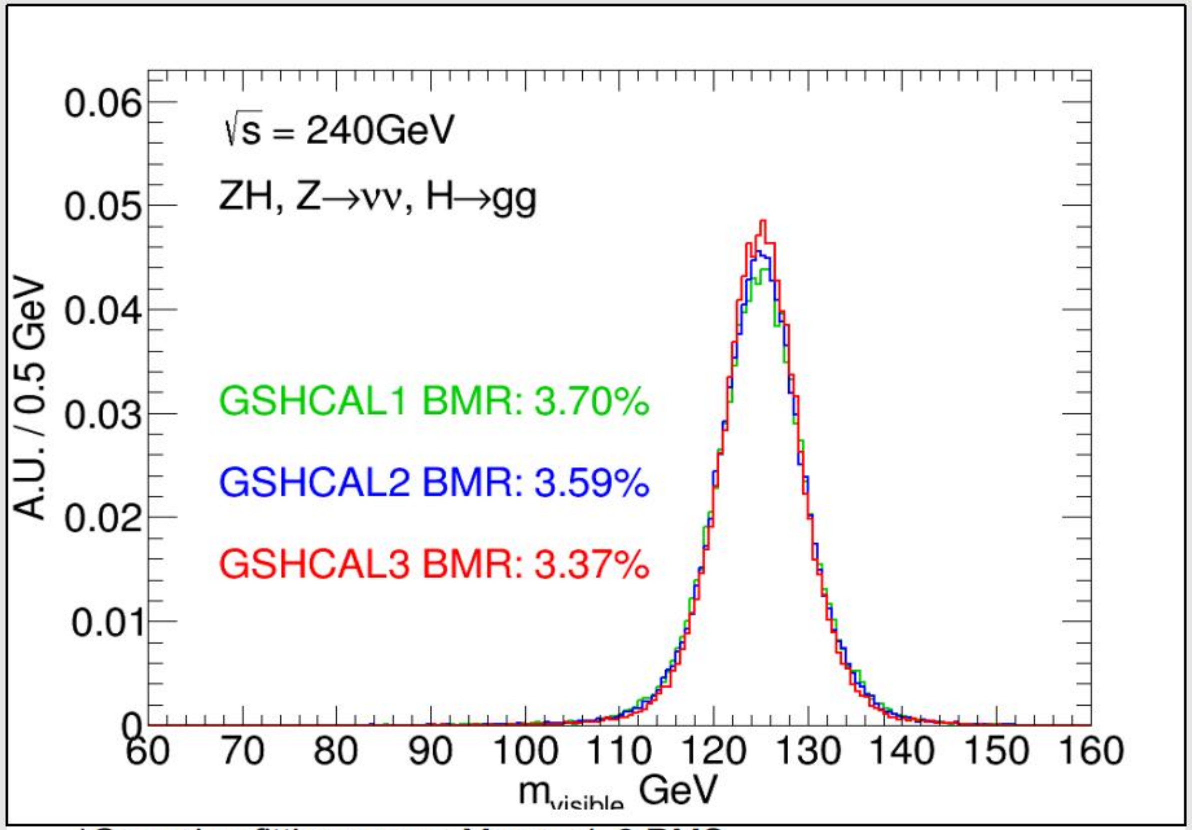
*Gaussian fitting range: Mean +/- 2 RMS

- By using a similar setup with the AHCAL, the GSHCAL can achieve a more compact structure and less readout channels, as well as a comparable PFA performance with the DHCAL

2.5 Different GSHCAL Designs

Nominal Setup

Parameter	GSHCAL1	GSHCAL2	GSHCAL3
Readout	Analog	Analog	Analog
Number of layers	40	40	40
Layer thickness	0.125 lambda (3mm GS +18.8mm Steel)	0.125 lambda (10mm GS +13.9mm Steel)	0.125 lambda (29.7 mm GS)
Total Nuclear Interaction Length	5 lambda	5 lambda	5 lambda
Transverse Cell Size	40x40 mm^2	40x40 mm^2	20x20 mm^2
Sensitive Material Density	6 g/cm^3	6 g/cm^3	6 g/cm^3
HCAL Thickness	873 mm	962 mm	1218 mm
HCAL Volume	13 m^3(GS) 81 m^3(Steel)	46 m^3(GS) 64 m^3(Steel)	159 m^3(GS)
Number of Cells	2.7×10^6	**2.9×10^6**	5.4×10^7



*Gaussian fitting range: Mean +/- 2 RMS

- The GSHCAL2 design is slightly thicker (+30 mm) than the AHCAL, BMR can reach ~3.6% （improved ~5%）
- The GSHCAL3 is a homogenous design, with which the BMR can reach ~3.4% and show ~10% improvement, but the total volume and readout channel will also increase significantly

Dead area of Barrel HCAL

layer	short length(cm)	cell nunber	abnormal cell	dead area(cm)
1	81.00	20	0	0.403
2	82.09	19	1	0.4851
3	83.17	18	2	0.5672
4	84.25	17	3	0.6493
5	85.33	21	0	0.7014
6	86.41	20	1	0.7835
7	87.50	19	2	0.8656
8	88.58	18	3	0.9477
9	89.66	22	0	0.9998
10	90.74	20	2	0.0819
11	91.82	19	3	0.164
12	92.91	23	0	0.2161
13	93.99	22	1	0.2982
14	95.07	21	2	0.3803
15	96.15	20	3	0.4624
16	97.23	24	0	0.5145
17	98.32	23	1	0.5966
18	99.40	22	2	0.6787
19	100.48	21	3	0.7608
20	101.56	25	0	0.8129
21	102.65	24	1	0.895
22	103.73	23	2	0.9771
23	104.81	26	0	0.0292
24	105.89	25	1	0.1113
25	106.9734	24	2	0.1934
26	108.0555	23	3	0.2755
27	109.1376	27	0	0.3276
28	110.2197	26	1	0.4097
29	111.3018	25	2	0.4918
30	112.3839	24	3	0.5739
31	113.466	28	0	0.626
32	114.5481	27	1	0.7081
33	115.6302	26	2	0.7902
34	116.7123	25	3	0.8723
35	117.7944	29	0	0.9244
36	118.8765	27	2	0.0065
37	119.9586	26	3	0.0886
38	121.0407	30	0	0.1407
39	122.1228	29	1	0.2228
40	123.2049	28	2	0.3049
41	124.287	27	3	0.387
42	125.3691	31	0	0.4391
43	126.4512	30	1	0.5212
44	127.5333	29	2	0.6033
45	128.6154	28	3	0.6854
46	129.6975	32	0	0.7375
47	130.7796	31	1	0.8196
48	131.8617	30	2	0.9017
total	5108.7528	1174	70	25.4328

mean length of trapezium:
25.4328+48*0.54=38.39
5108+48*0.54=5134

38.39/5134=0.75%

1174*(4.03^2-4^2)+
70*(4.03*5.03-4*5)=302

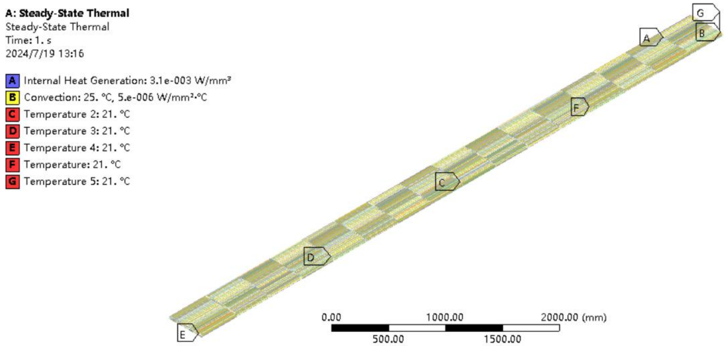
302/(5134*4.03)=1.4%

2.4*2*48/5134=4.5%

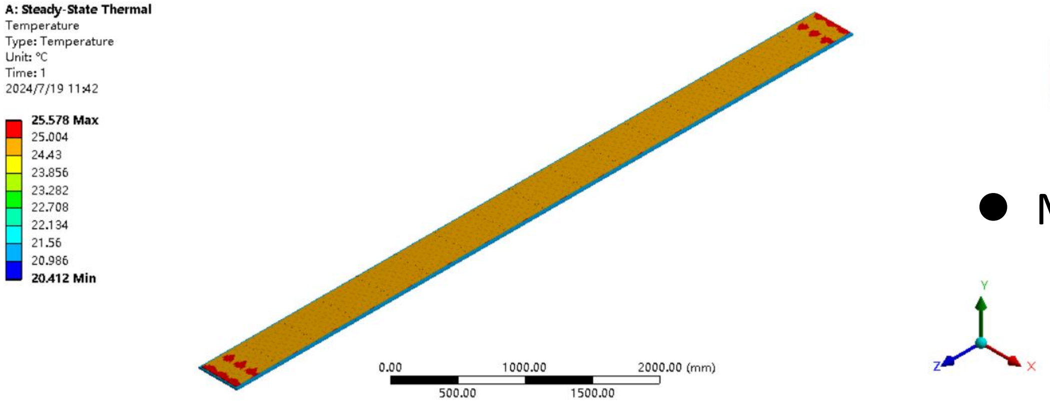
Barrel HCAL preliminary cooling design

From Yatian

Static temperature simulation result



Boundary conditions

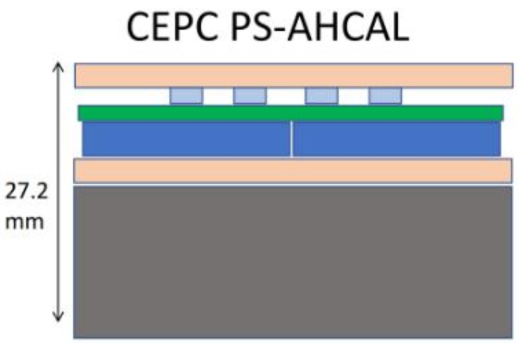


Temperature distribution of the model

- Max. temperature: **25.58℃**

Barrel HCAL preliminary mechanical design

Based on PS-AHCAL

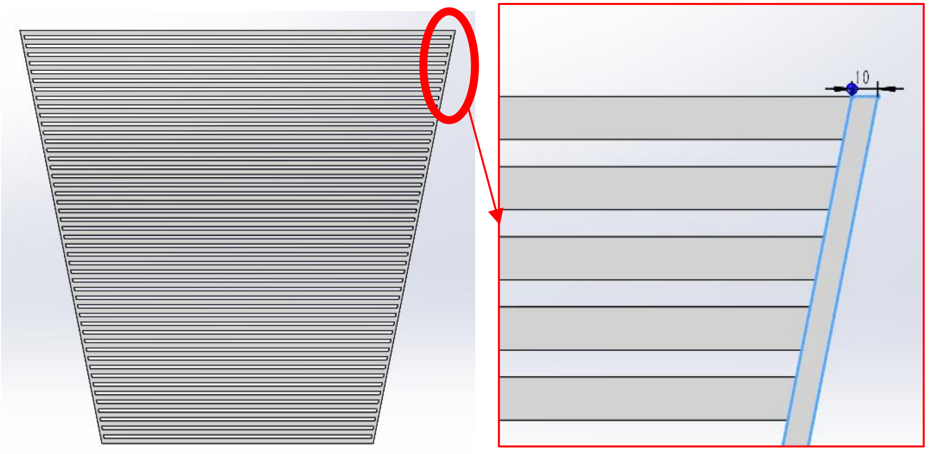


- Each PS is 4cm×4cm×3mm

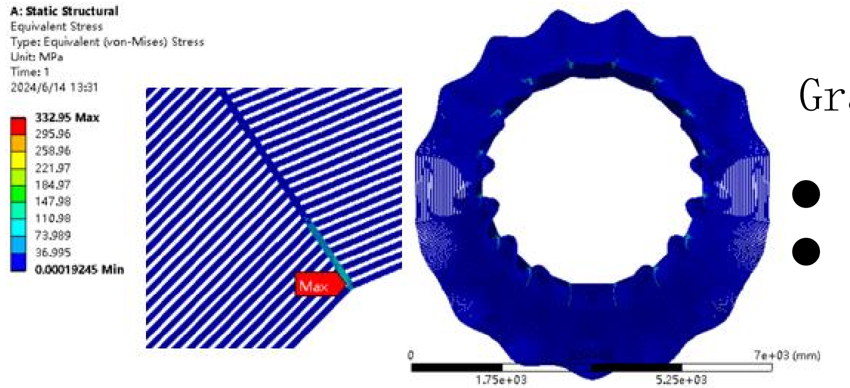
Statistics

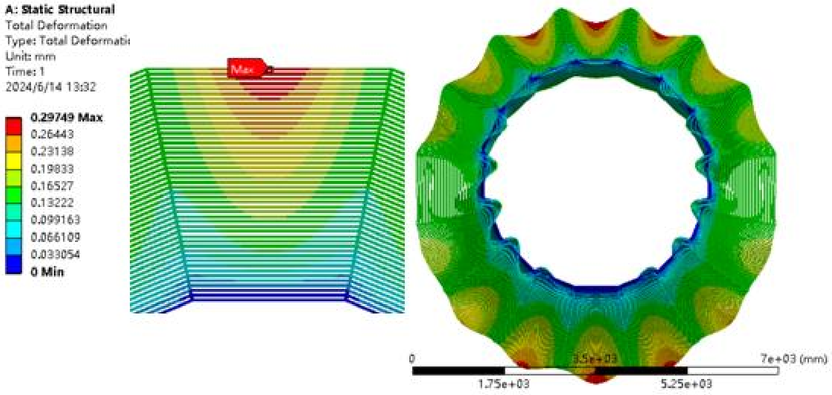
- Left width: 0.47mm to 38.5268mm, average is 19.78mm (can be used for reference thickness of side support)
- Possible support area ratio :Left width/ Layer width=1.78%
- Total SiPM for 1 division : 211232
- Total channel: **3.38 M**

Mechanical structure design V1



- Add two side plates, each one is 10mm in thickness, totally 20mm≈19.78mm
- No division in axial
- Support front and back end





Gravity condition

- Max. stress is 332.95MPa
- Max. deformation is 0.3mm

Disadvantage

- Stress is larger than allowable stress
- All absorption layers need to connect with side plates first, and then insert active layers from front end