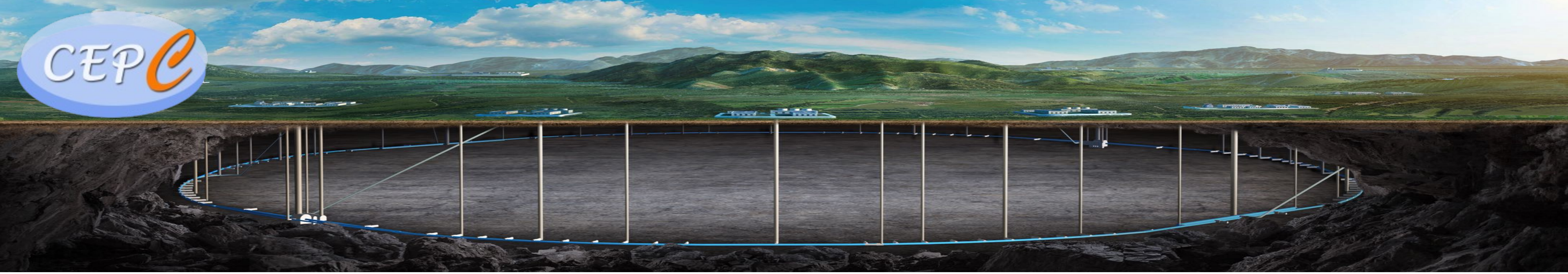


CEPC HCAL Detector

Yunlong Zhang

on behalf of CEPC calorimeter group

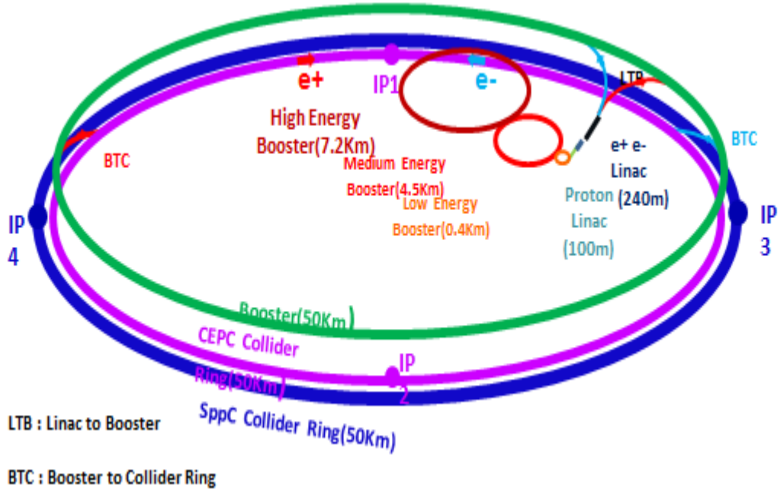
State Key Laboratory of Particle Detection and Electronics

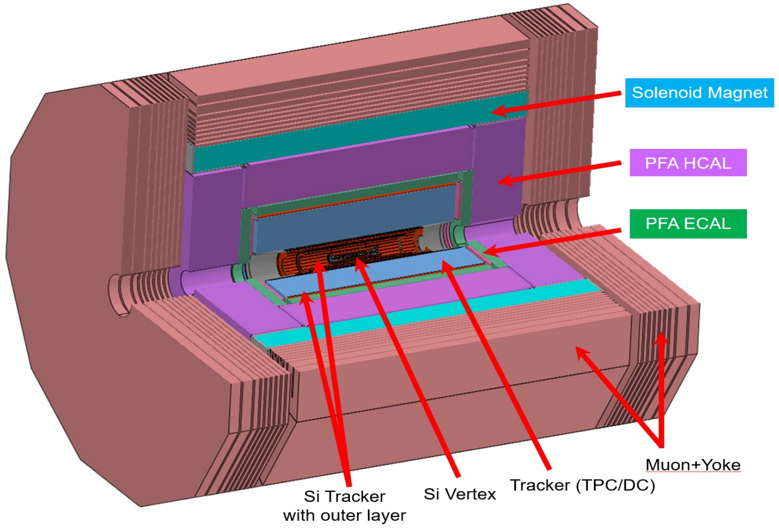
University of Science and Technology of China

Content

Introduction

- Circular Electron Positron Collider (CEPC)
  - $E_{cm} \approx 240$GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$ can also rum at the Z-pole
  - Precision measurement of the Higgs boson (and the Z boson)





CEPC detector concept

Challenges:

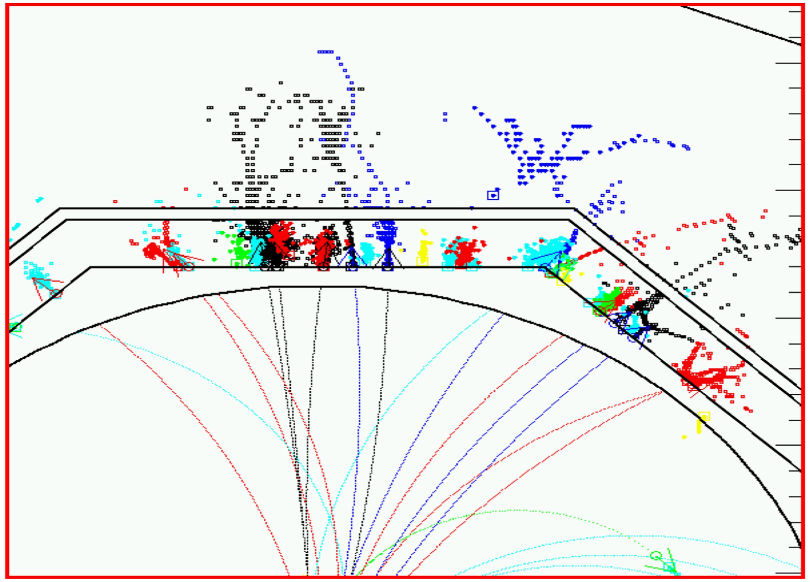
- **Momentum:** $\sigma_{1/p} < 5 \times 10^{-5}$ GeV^{-1}
- **Impact parameter:** $\sigma_{r\phi} = 5 \oplus 10/(p \cdot \sin^{\frac{3}{2}}\theta)\ \mu m$
- **Jet energy:** $\frac{\sigma_E}{E} \approx 3 - 4\%$

Requirement of CEPC HCAL

- 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%

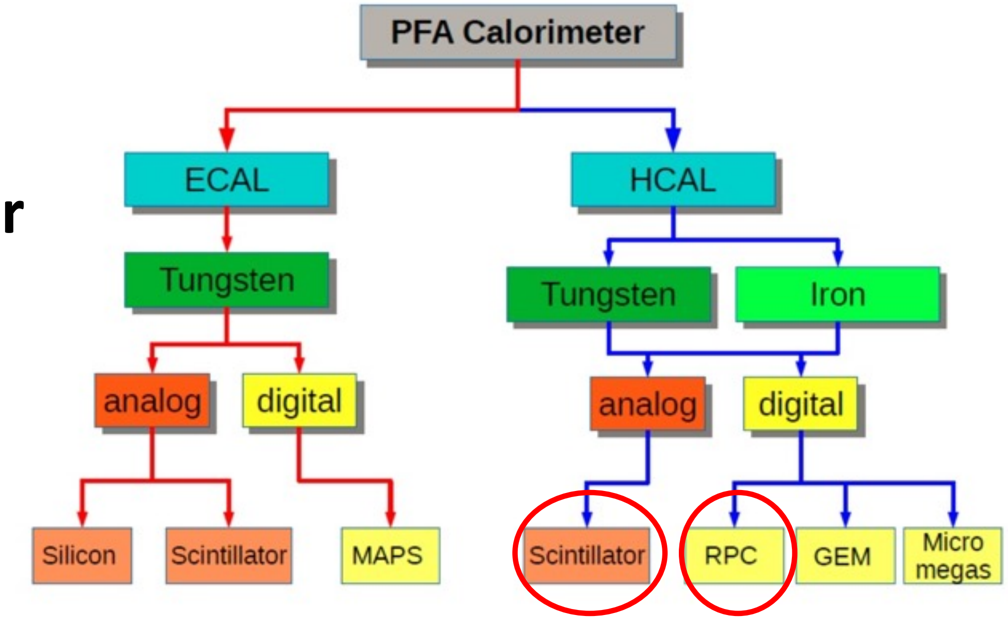
What kind of Calorimeter do we need for CEPC?

- The Particle Flow Algorithm (PFA) calorimeter concept was proposed
  - High granularity
  - Good track finding
  - Good energy resolution



Technology survey and our choices

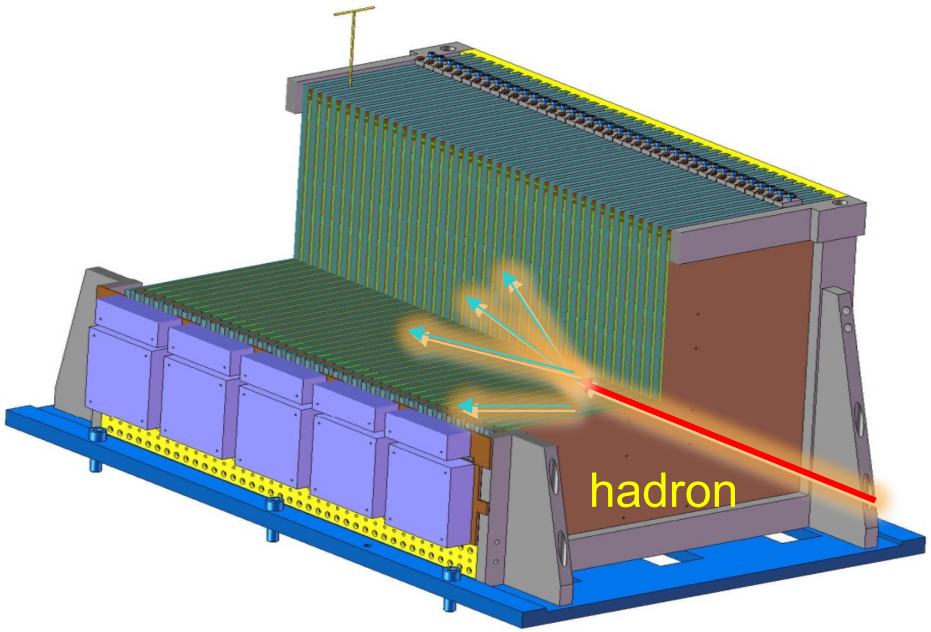
- **Sampling, Imaging Calorimeter**
  - AHCAL-PS
    - Analog readout, based-on plastic scintillator
  - AHCAL-GS
    - Analog readout, based-on scintillator glass



AHCAL-PS Prototype

- **We have developed a AHCAL-PS prototype**

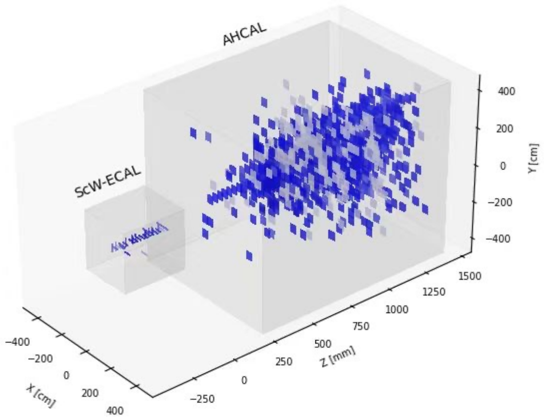
Calo	layers	material	Absor.	Granularity	Elec.	thickness	Resolution	weight
AHCAL	40	PSD+SiPM	Fe	40×40 mm^2	SP-2E	4.6 NIL	60%@ 1 GeV	5.0 T

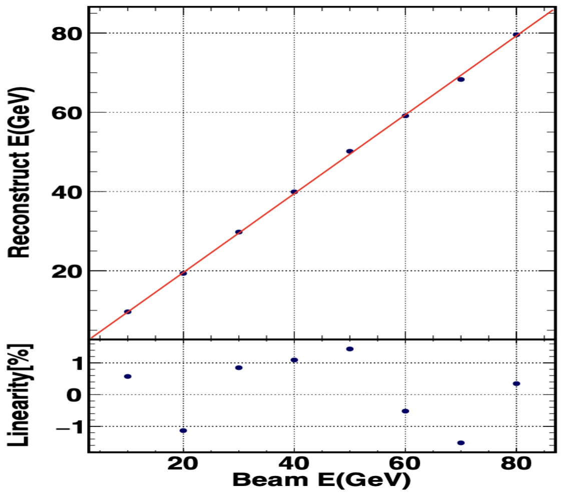


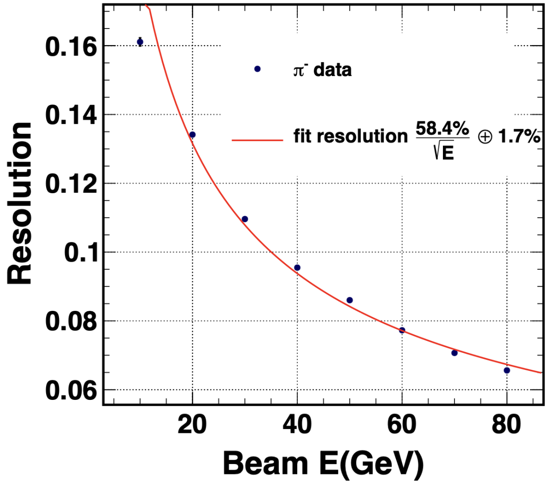
AHCAL-PS Beam Test

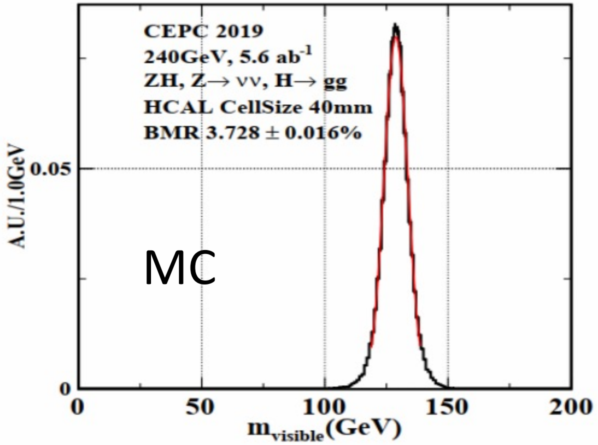
- Energy linearity: better than 1.5%
- Energy resolution is $\frac{58.4\%}{\sqrt{E}} \oplus 1.7\%$

Pi Beam Data, 10 – 80 GeV







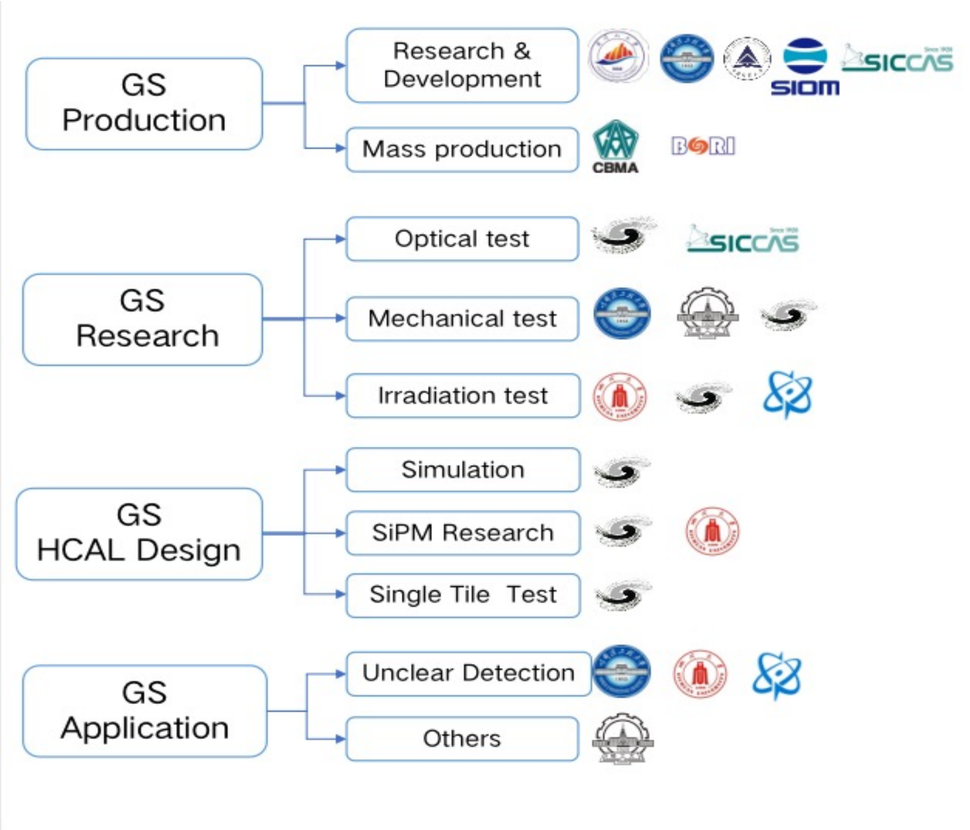


AHCAL-GS

- How to improve the AHCAL energy resolution
  - Select high density and cheap scintillators

Plastic Scintillator		Glass Scintillator		Crystal Scintillator	
light yield	★★	light yield	★	light yield	★★★
Fast decay	★★★	Fast decay	★★	Fast decay	★★
Low cost	★★★	Low cost	★★★	Low cost	★
Large Density	★	Large Density	★★	Large Density	★★★
Energy resolution	★	Energy resolution	★★	Energy resolution	★★★
Large size	★★★	Large size	★★★	Large size	★

Large Area Glass Scintillator Collaboration



Institute of High Energy Physics，CAS
中国科学院高能物理研究所

Jinggangshan University
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China Building Materials Academy
中国建筑材料研究院

China Jiliang University
中国计量大学

Harbin Engineering University
哈尔滨工程大学

Harbin Institute of Technology
哈尔滨工业大学

Sichuan University
四川大学

Shanghai Institute of Ceramics，CAS
中国科学院上海硅酸盐研究所

Shanghai Institute of Optics and Fine Mechanics，
中国科学院上海光学精密机械研究所

CNNC Beijing Unclear Instrument Factory
中核（北京）核仪器有限责任公司

闪烁玻璃合作组
Glass Scintillator Collaboration

Spokesperson： Sen QIAN

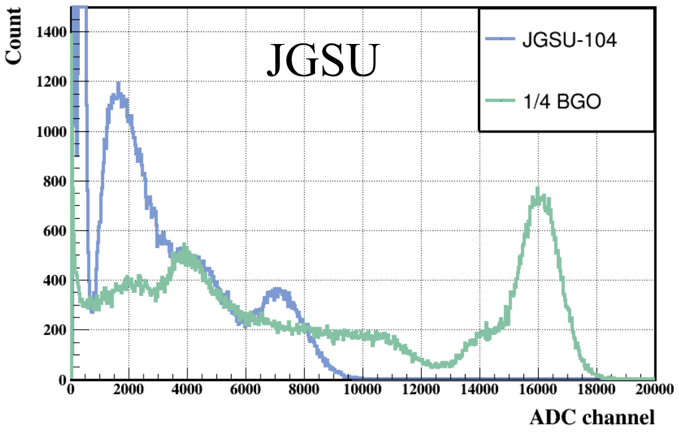
-- The Glass Scintillator Collaboration Group established in Oct.2021；

-- There are 3 Institutes of CAS, 5 Universitys, 3 Factorys join us for the R&D of GS;

GS samples study

Small-Size

- **Size=5*5*5 mm³**
- Density~6.0 g/cm³
- LY~1000 ph/MeV
- ER=30.3%
- LO in 1μs=982 ph/MeV
- Decay=36 (8%), 105 ns



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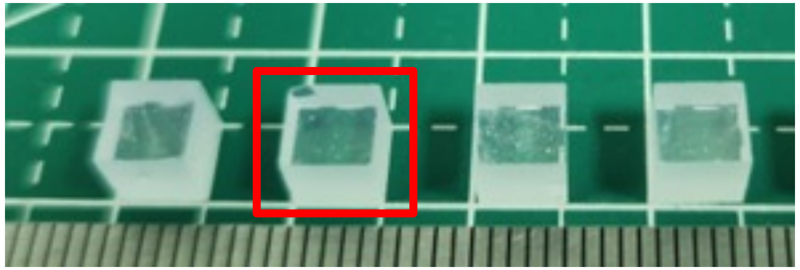
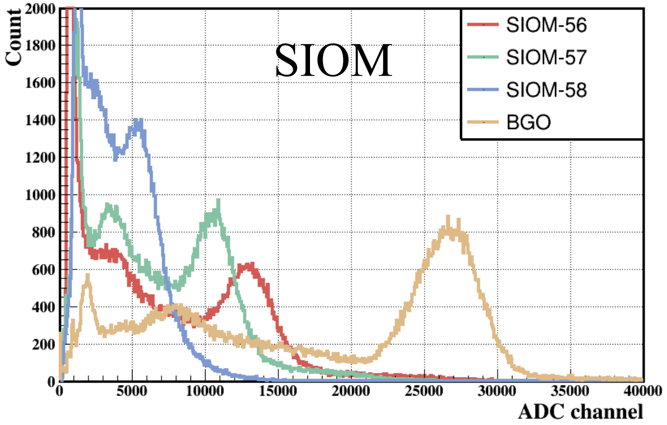


Large-Size

- **Size=40*40*10 mm³**
- Density=6.0 g/cm³
- LY ~1200 ph/MeV
- ER=33.0%
- LO in 1μs=607 (51%)
- Decay=117 (3%), 1368 ns



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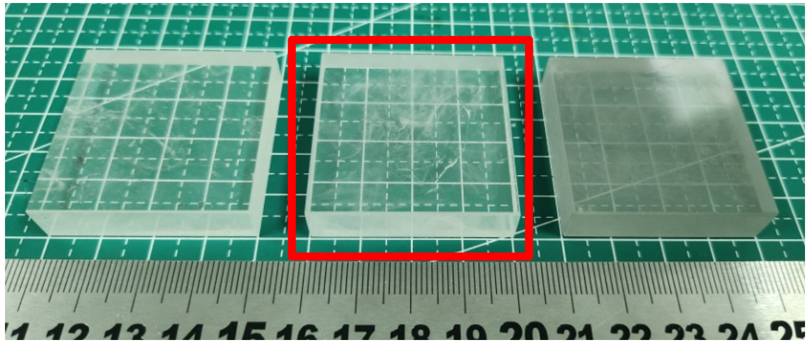
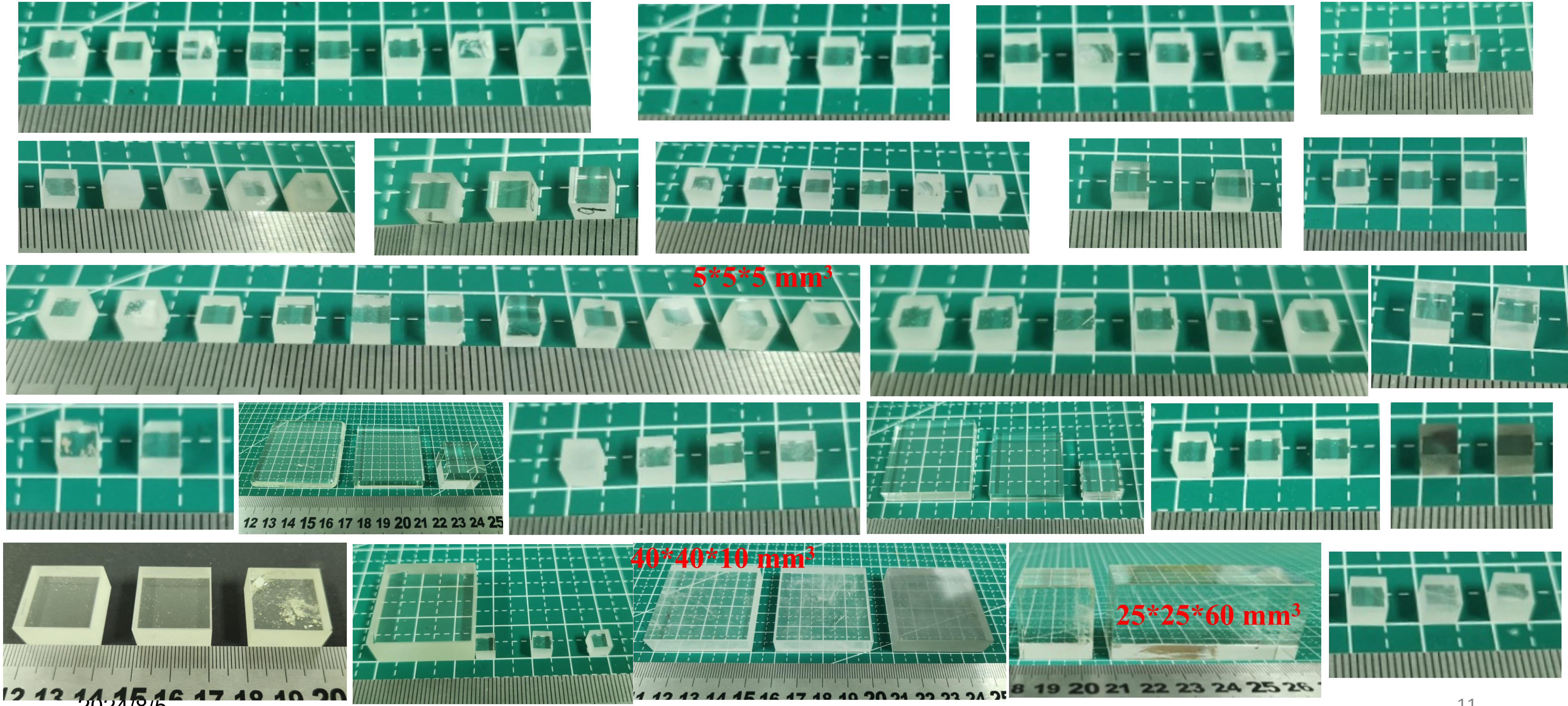
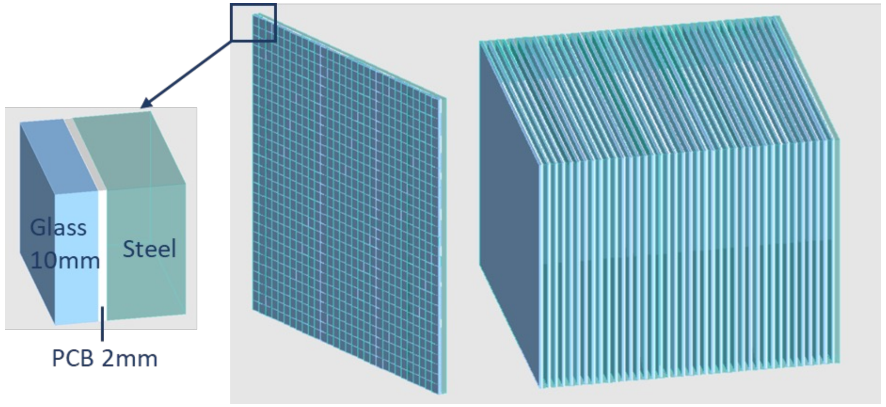


GS samples mass production

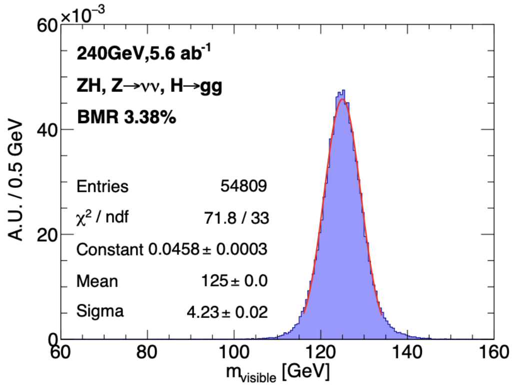


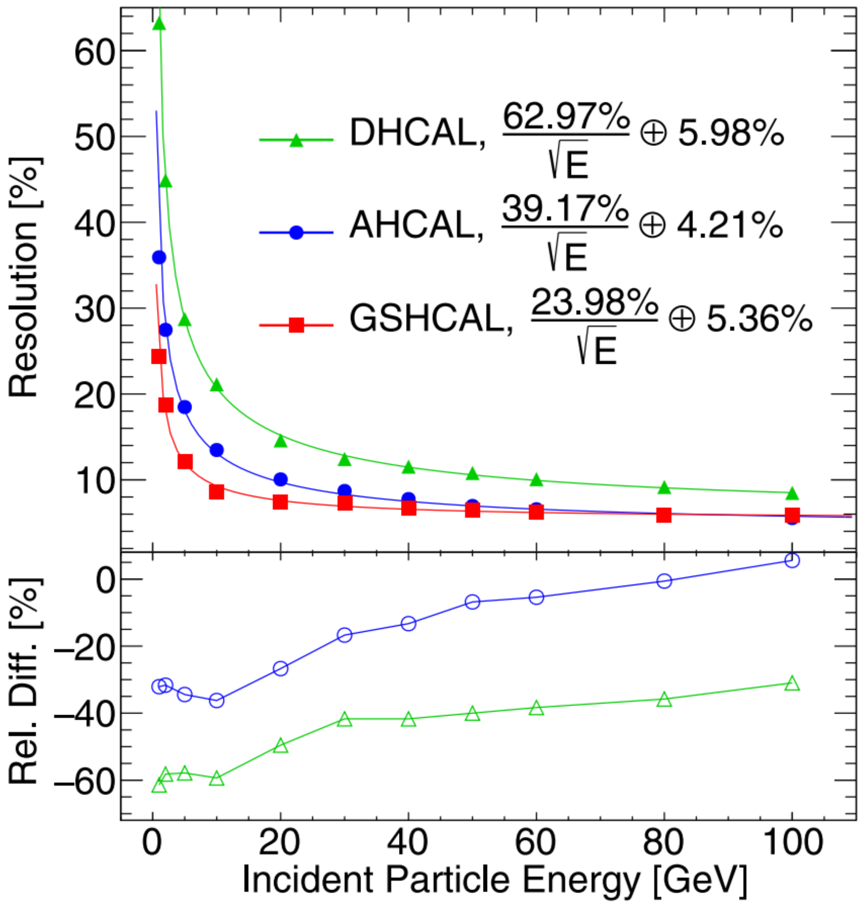
AHCAL-GS Simulation study

- GS-AHCAL design optimizations:
  - **Density: 6 g/cm^3**
  - **Thickness: 10 mm**
- Beam test of glass tiles
  - MIP response:
    - **71-96 p.e./MIP in 40*40*10 cm^3**



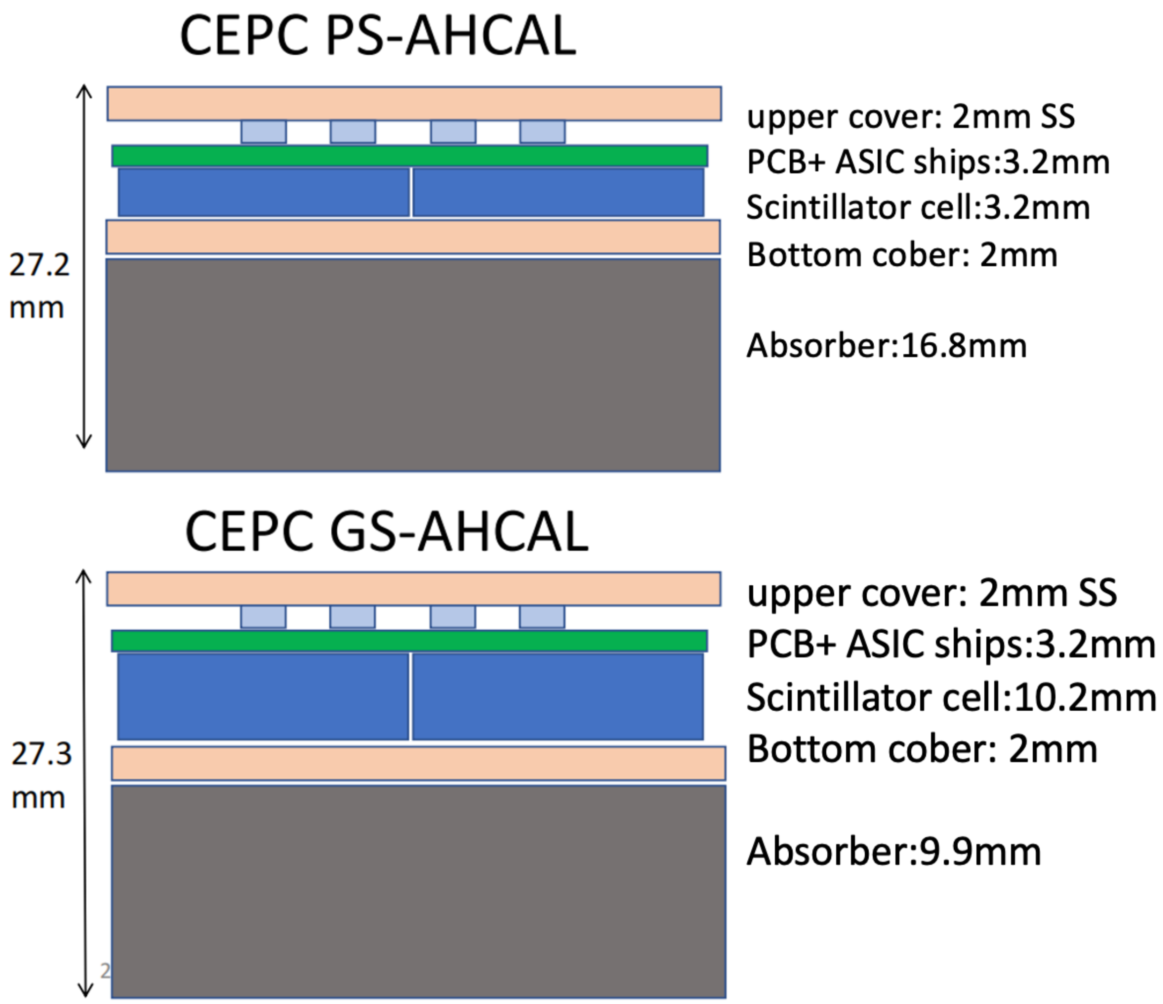
BMR result： 3.38%





The similarities between the two choices

- Both the PS and GS are analog calorimeter based on scintillator
- the photon device, the electronics design are much similar
- It is very convenient to replace the scintillator with glass while the glass is mature

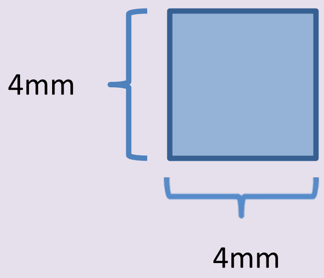


Main Technical Challenges

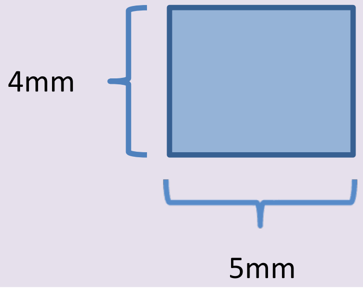
- The biggest challenge: **high granularity, 3D, large scale HCAL, scintillator glass**
- Technical innovations created to meet the challenge
  - Technique for **large scale production of high quality scintillator tiles** in a low-cost way
  - Highly integrated, **fully embedded and scalable electronics**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

AHCAL Barrel Geometry design in CEPCSW

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



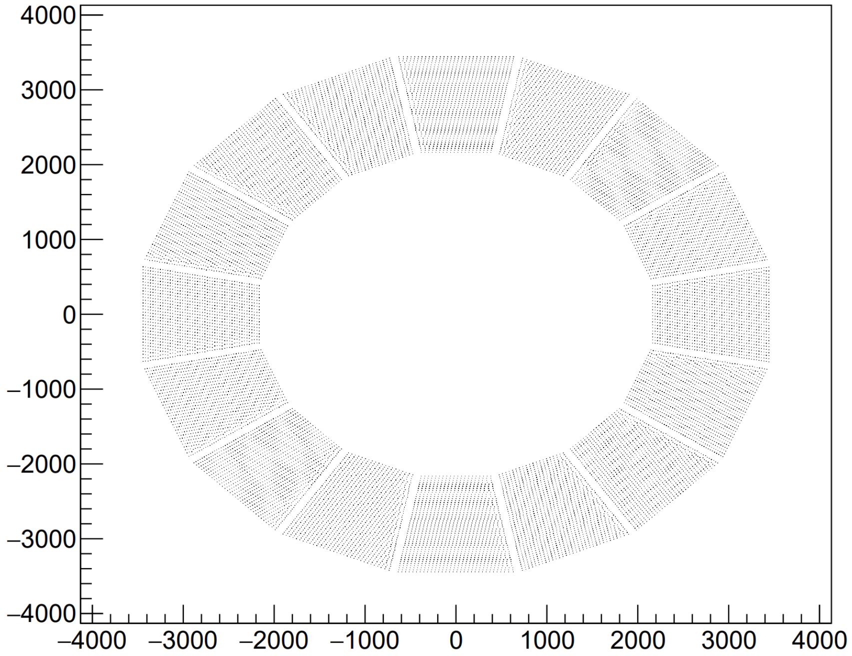
normal scintillator cell
$40\times40\times3\ mm^3$



abnormal scintillator cell
$40\times50\times3\ mm^3$

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

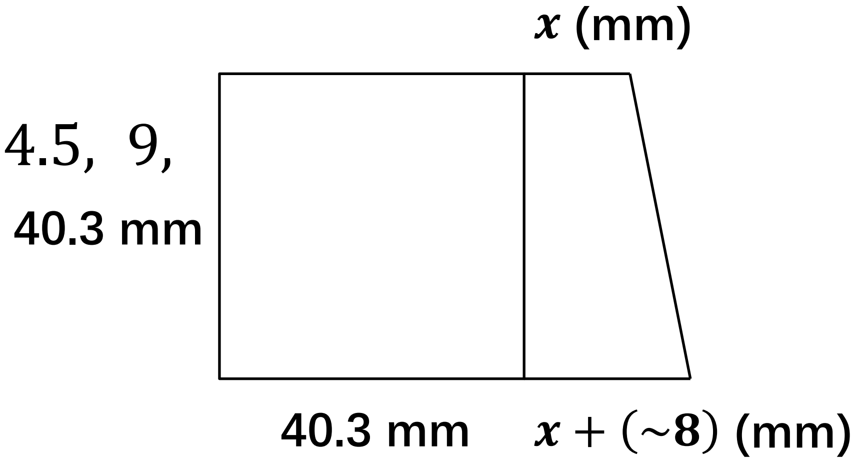
AHCAL Barrel can initially work in CEPCSW



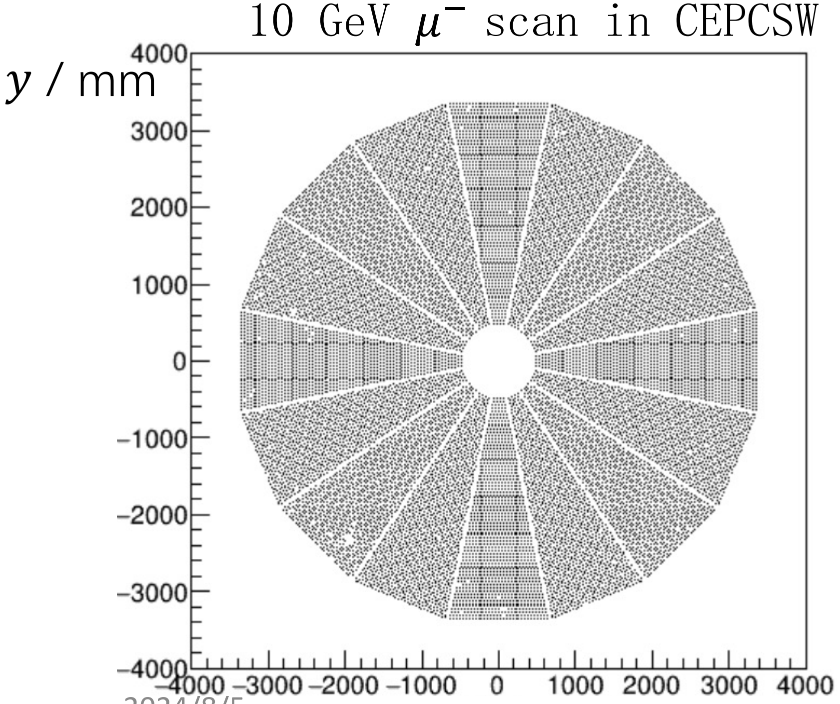
Hitmap in xy plane using muon scan

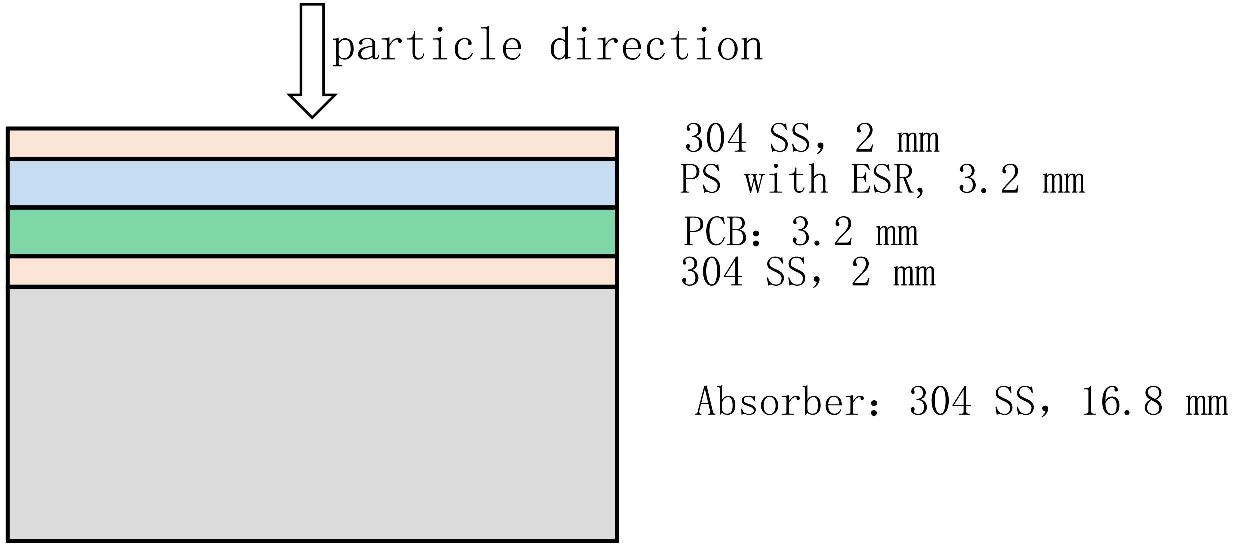
AHCAL Endcap Geometry design in CEPCSW

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

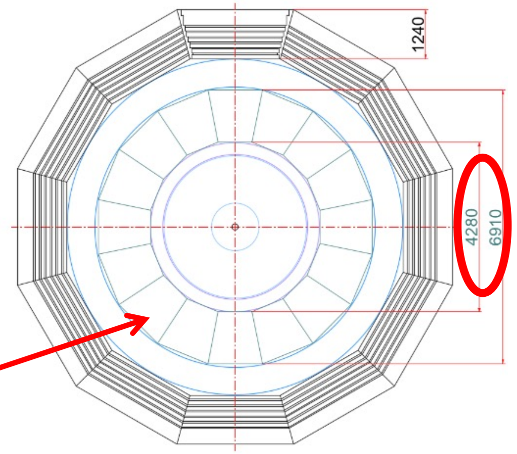


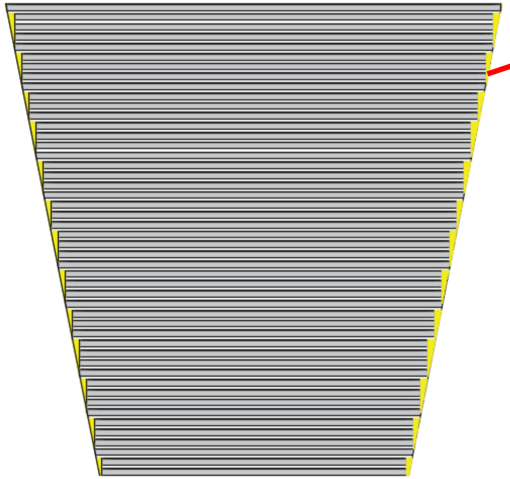
AHCAL Barrel can initially work in CEPCSW





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

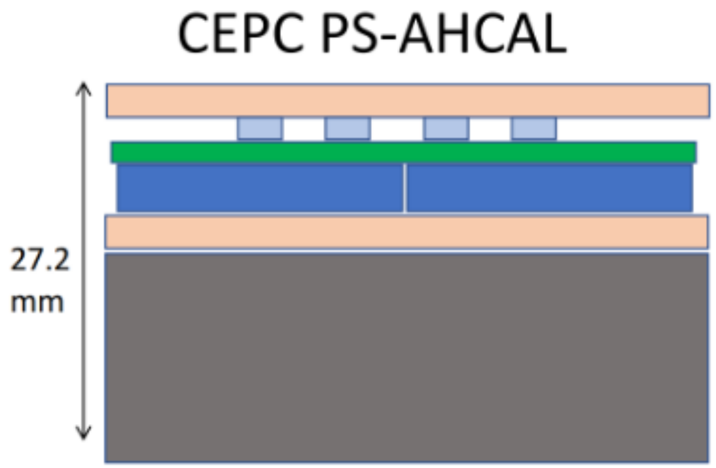
- Cell size： 4cm×4cm×3mm

Channel number

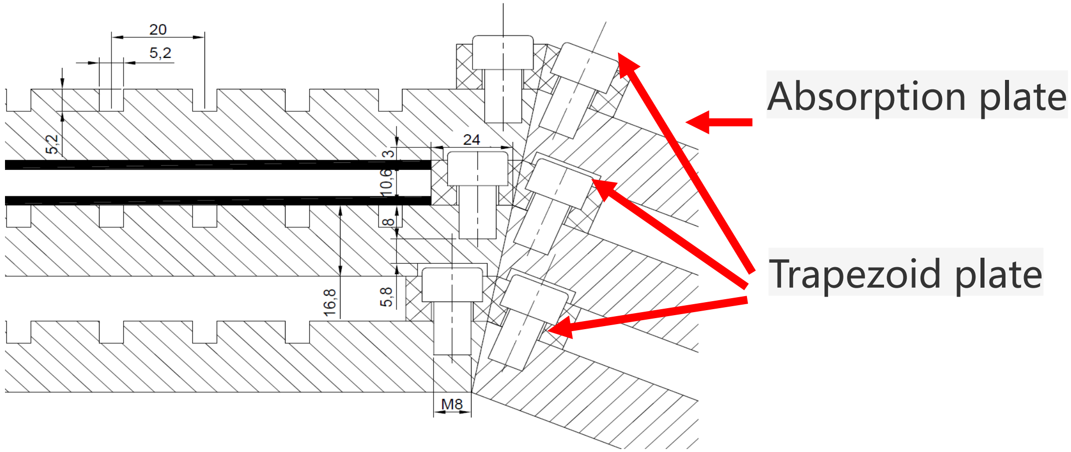
- Channels for 1/16 section : **211.2 k**
- Total channels: **3.38 M**

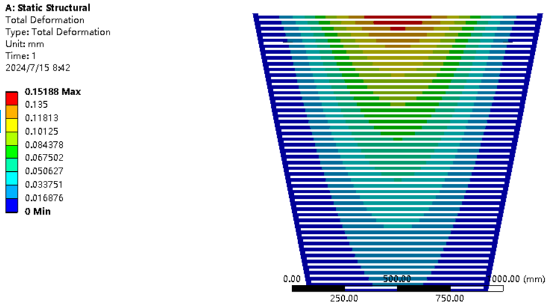
Weight

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



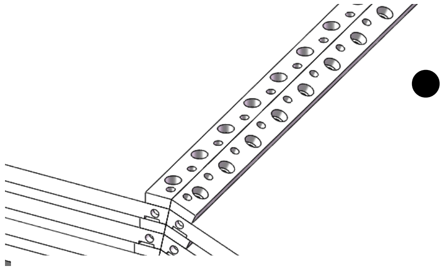
Barrel HCAL preliminary mechanical design



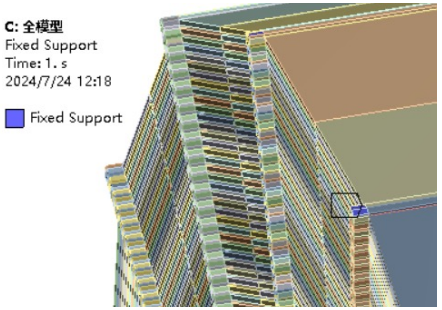


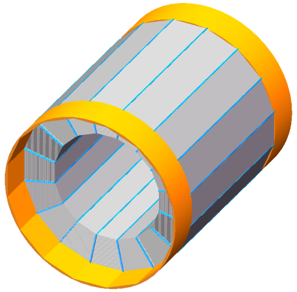
One section assembling condition under gravity

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

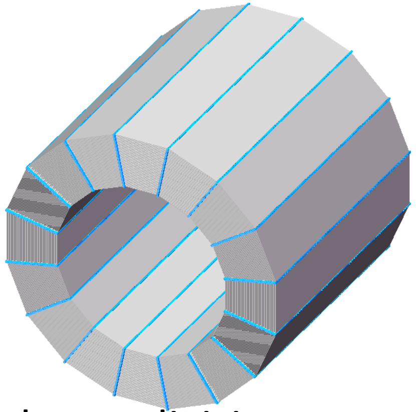


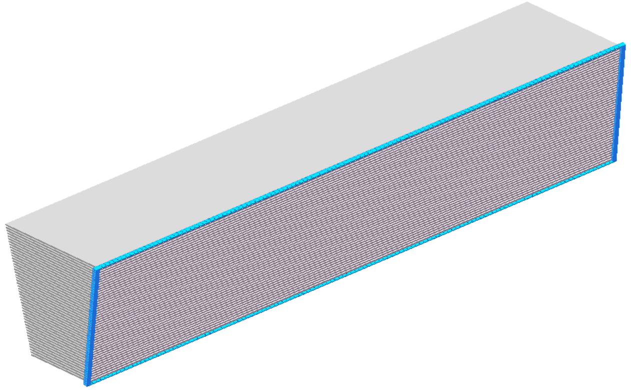
- One trapezoid plate connects with the upper and lower absorption layer by bolts

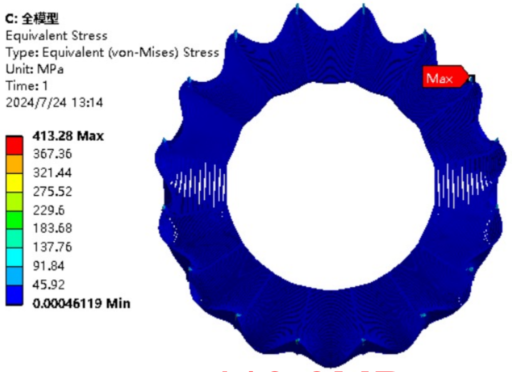


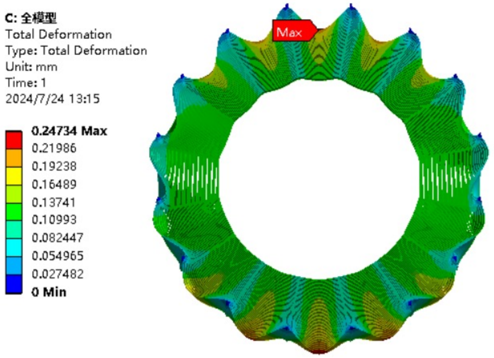


General model: Fix support applied on the top surface of each end







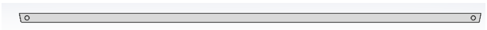


Gravity condition

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

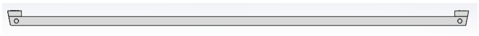
Mechanic installation scheme

①



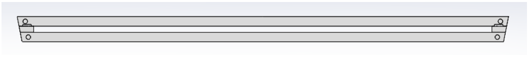
First absorption layer

② First active layer



③

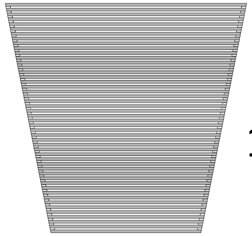
④



Second absorption layer

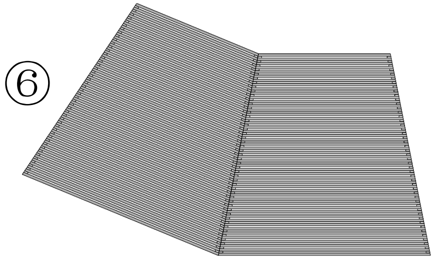
First trapezoid plate layer

⑤



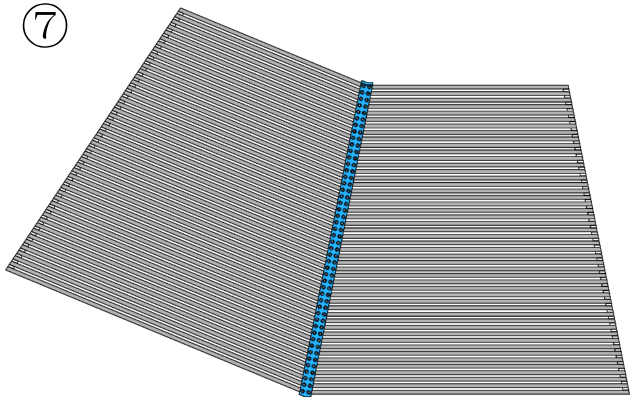
1 division

⑥



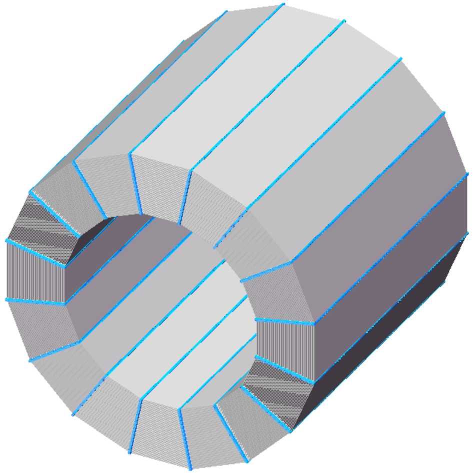
2nd division is in position by crane and tooling

⑦



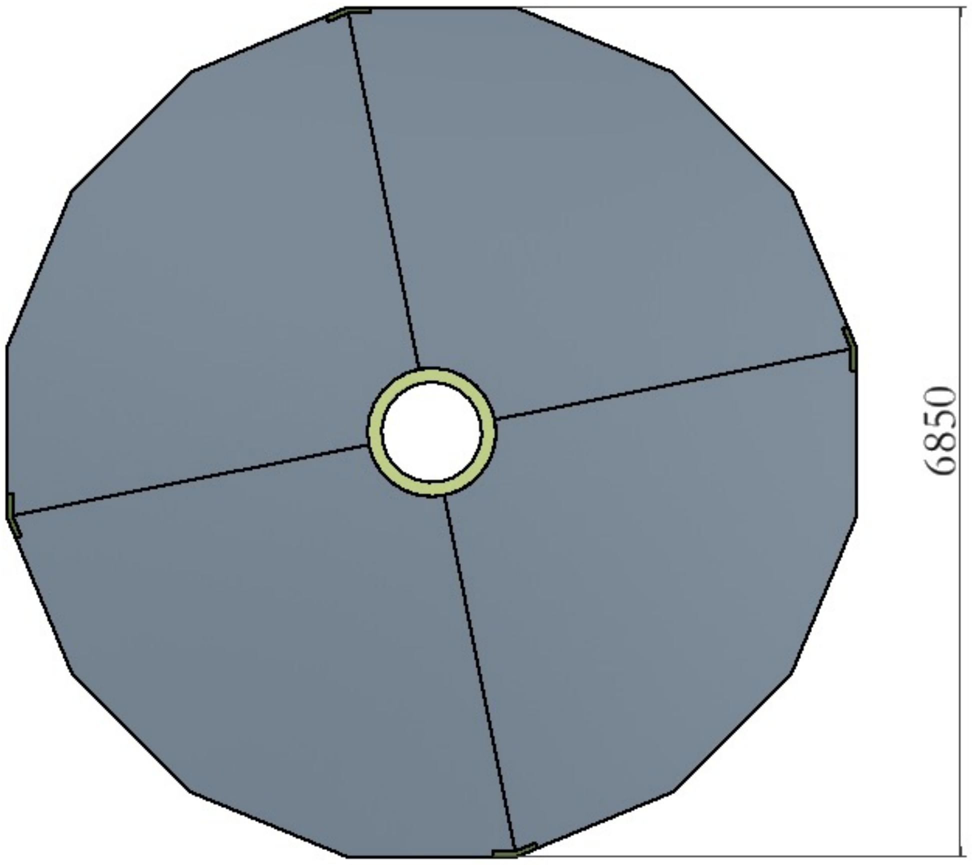
Fixing two division with edge sealings

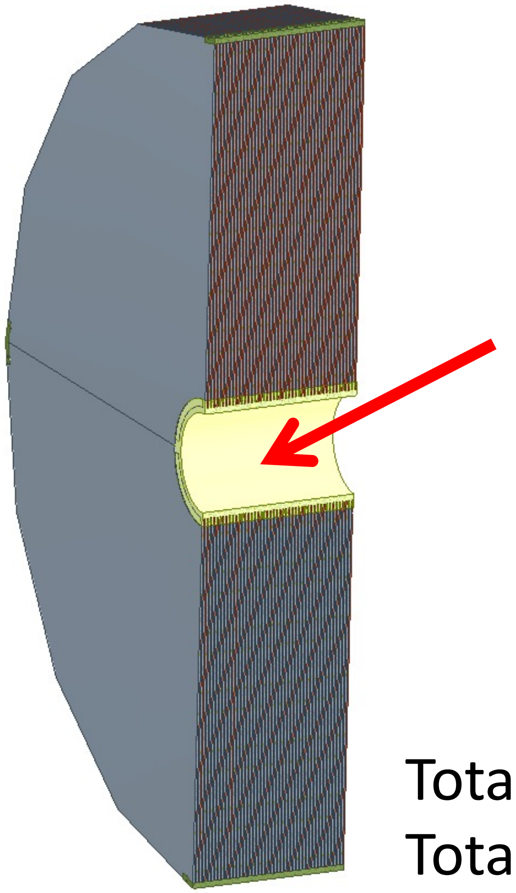
⑧

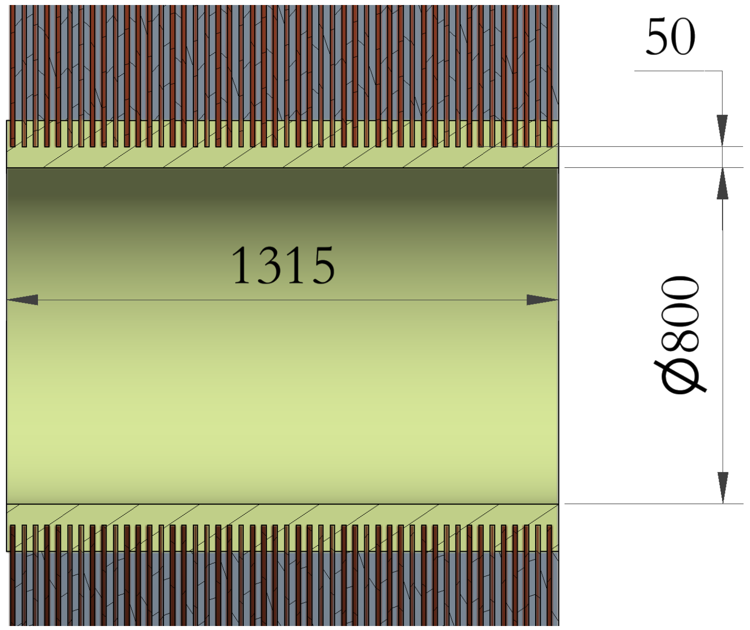


Finish

HCAL endcap mechanic preliminary design







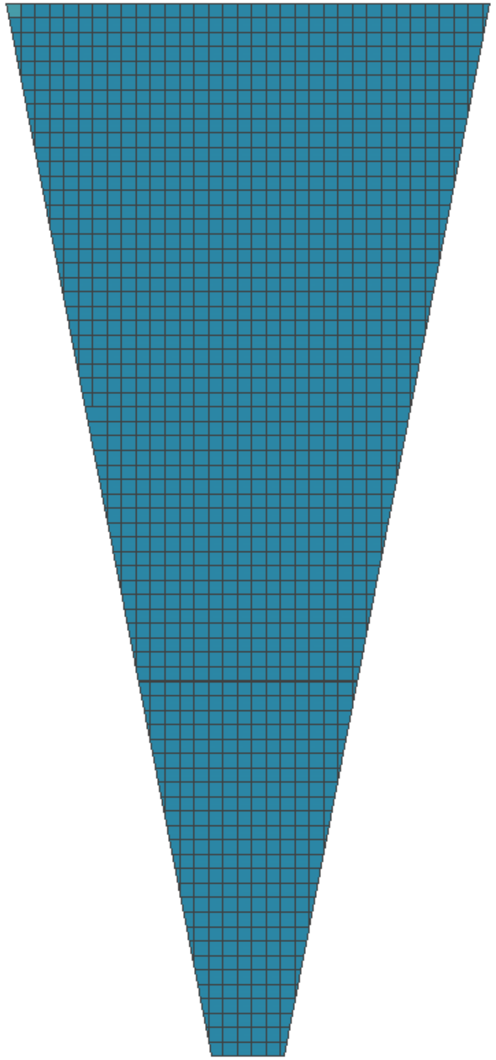
Total channel number： **1.12 M×2**

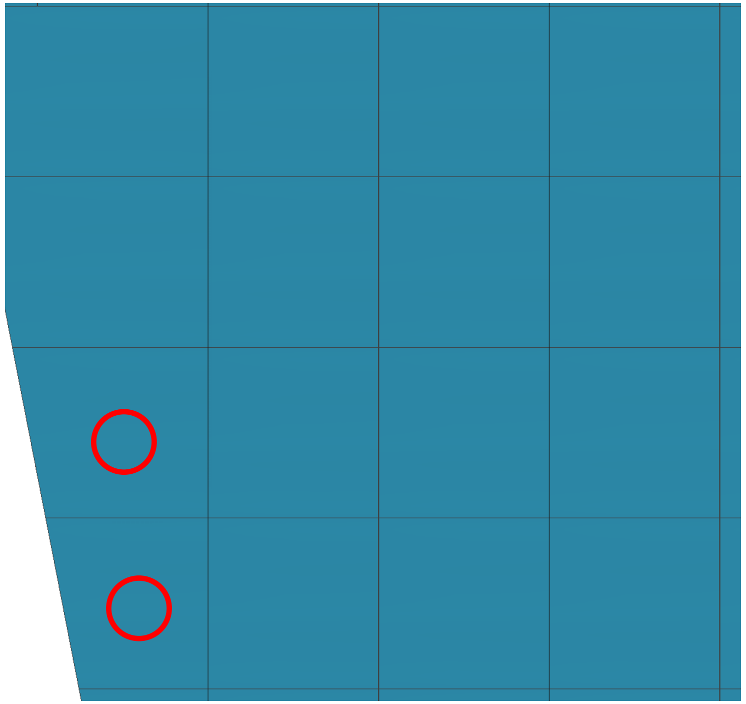
Total weight: **320 tons**

The active layer: **16 sections**

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

HCAL endcap scintillator preliminary arrangement





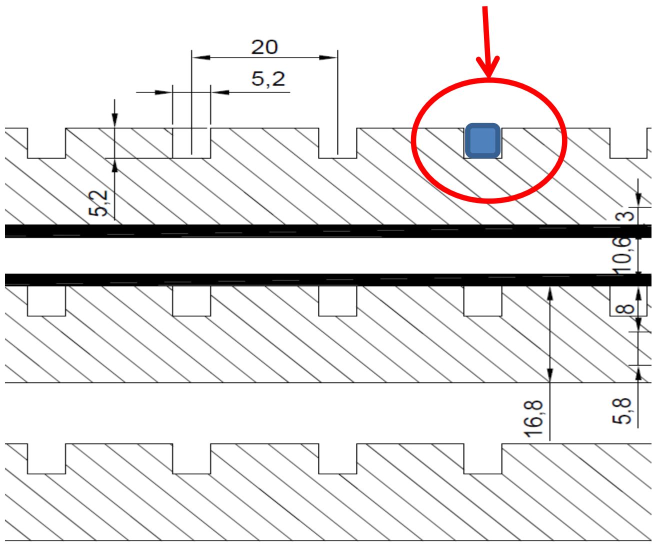
- 1/16 session : 73 Line scintillator
- The basic size of scintillator 40mm × 40mm × 3mm
- At the edge, the trapezoidal scintillator is used.
- The dead area: <1%

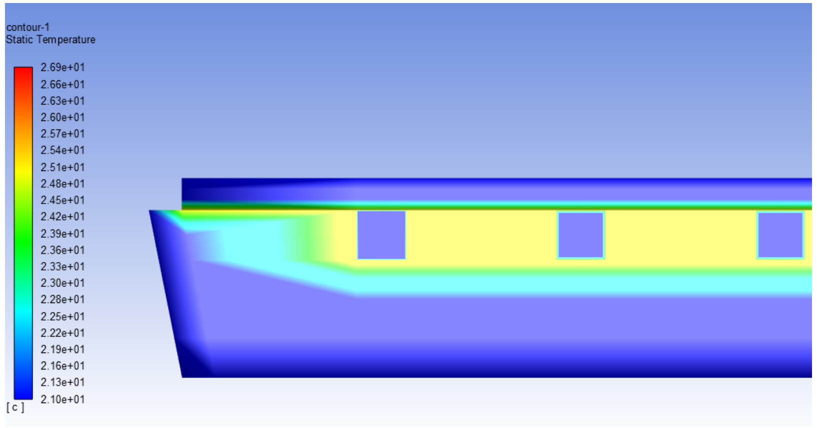
Barrel HCAL preliminary cooling design

Requirement for cooling

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

Cooling pipe



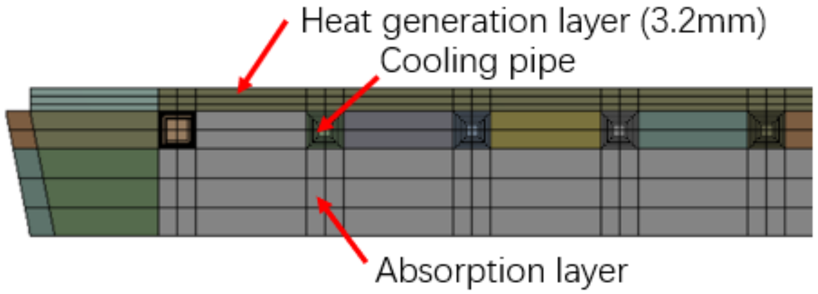


Temperature distribution along thickness direction

- Max. temperature: **25.58℃**

Fluid flow (fluent) simulation

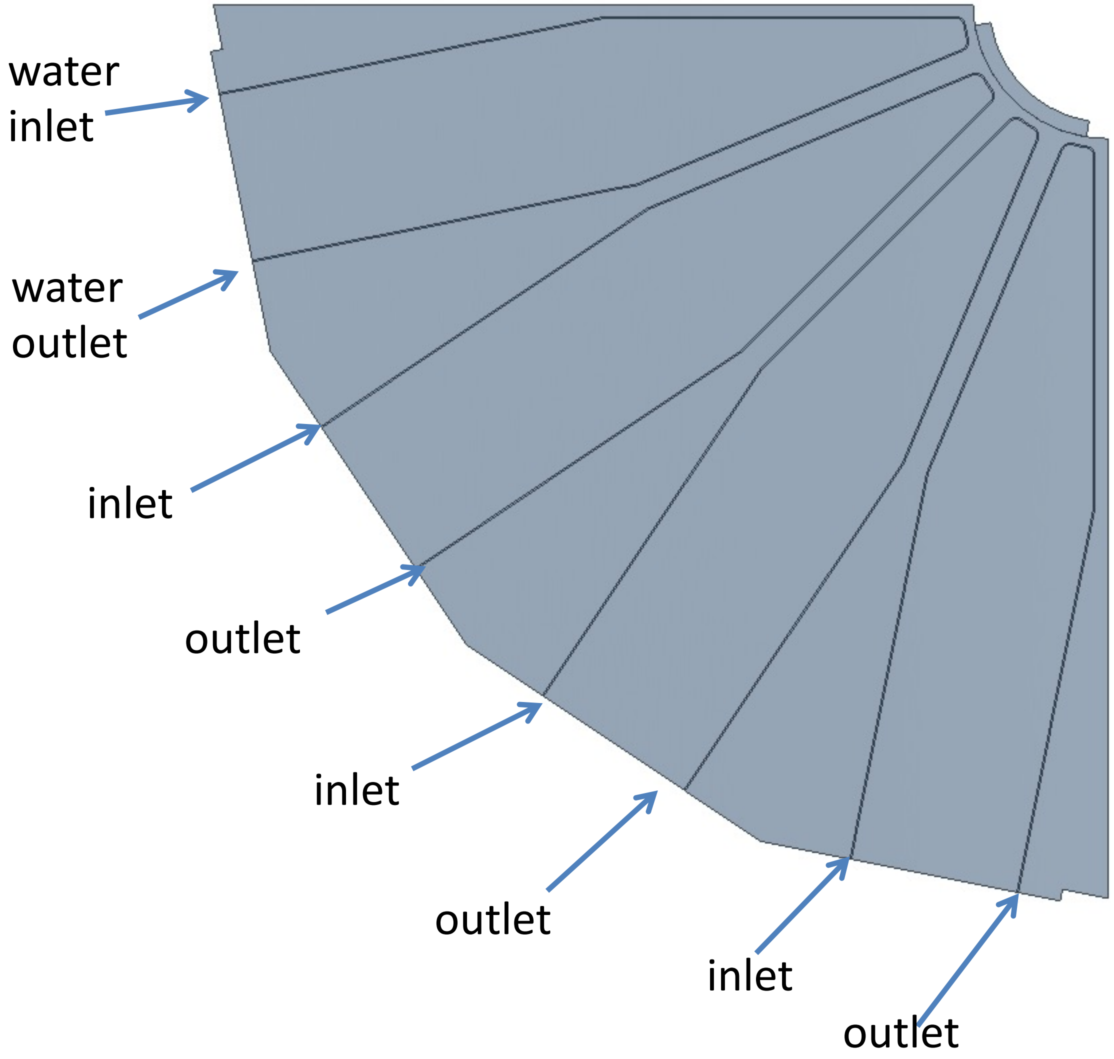
- Water inlet temperature: 21℃
- Surrounding temperature:25℃



Model

- Model including absorption layer, cooling pipe, cover plate, PCB, PS, chip
- Both inlet and outlet are 21℃

HCAL endcap preliminary cooling design

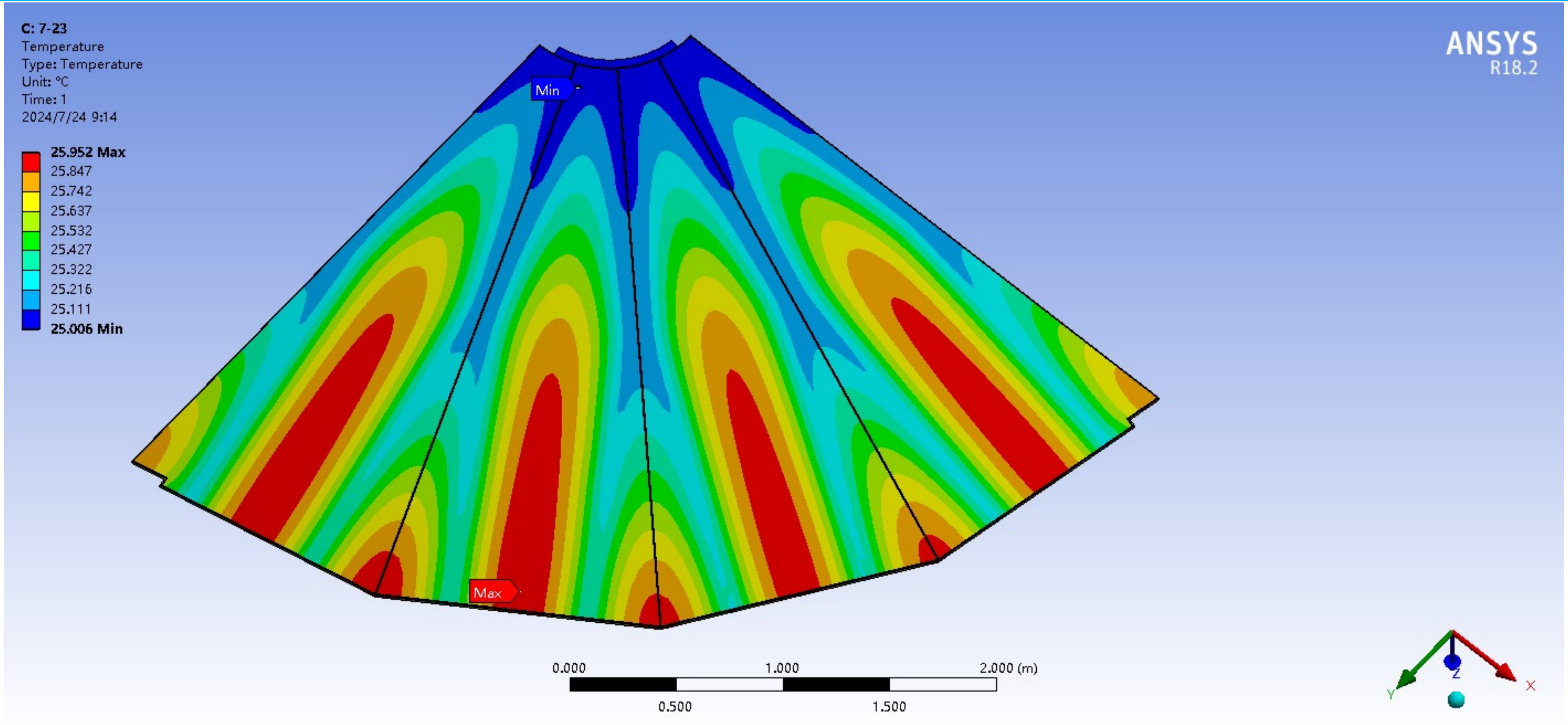


- Diameter of cooling Pipe： 5mm
- Each 1/16 session has one cooling pipe .
- The cooling effect is simulated for 1/4 detection area.

Heat source: **15mw/ch**

Water temperature: **25 °C**

HCAL endcap cooling calculation

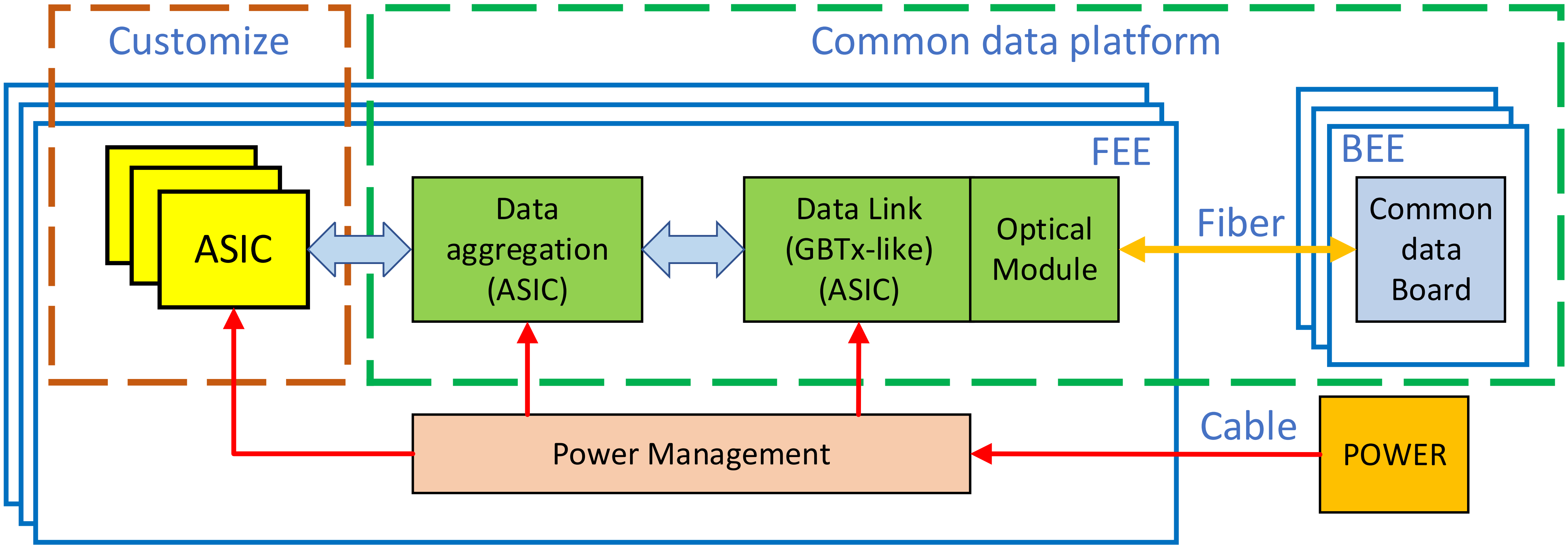


Water temperature： **25 °C**

Temperature range： **25 °C<T<26 °C**

Temperature rise： <1 °C

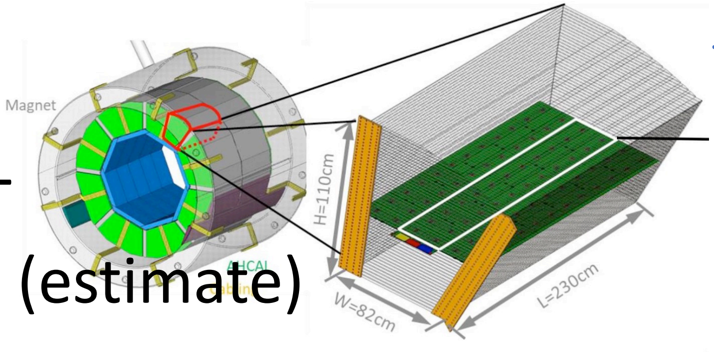
Electronics diagram for HCAL

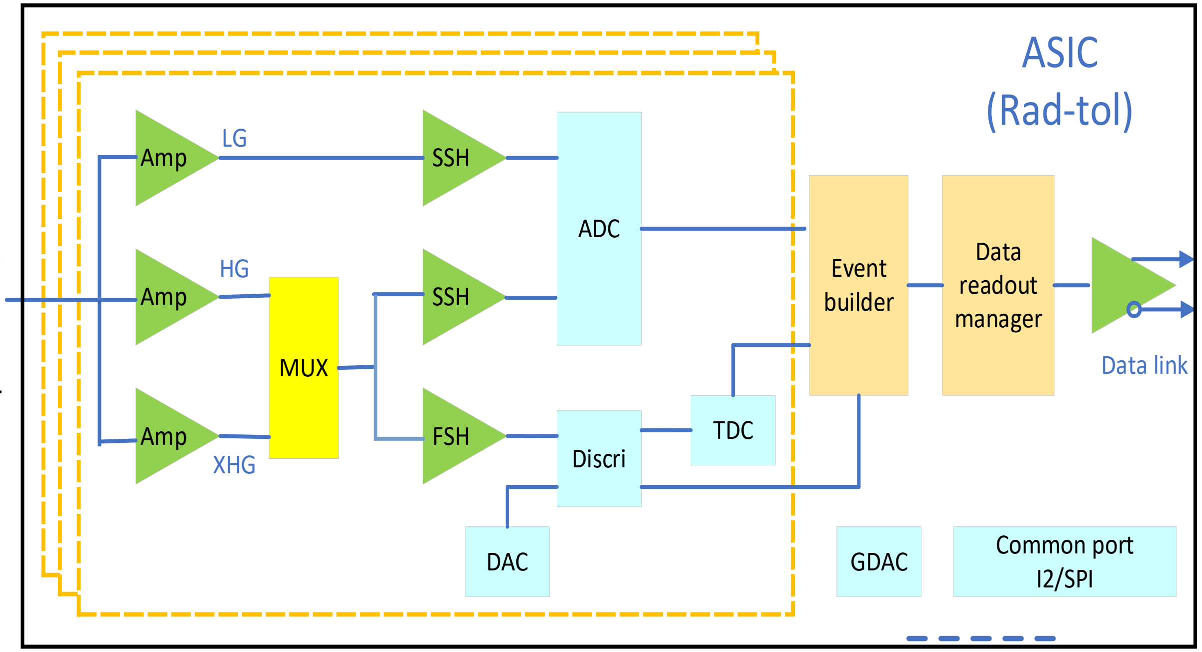


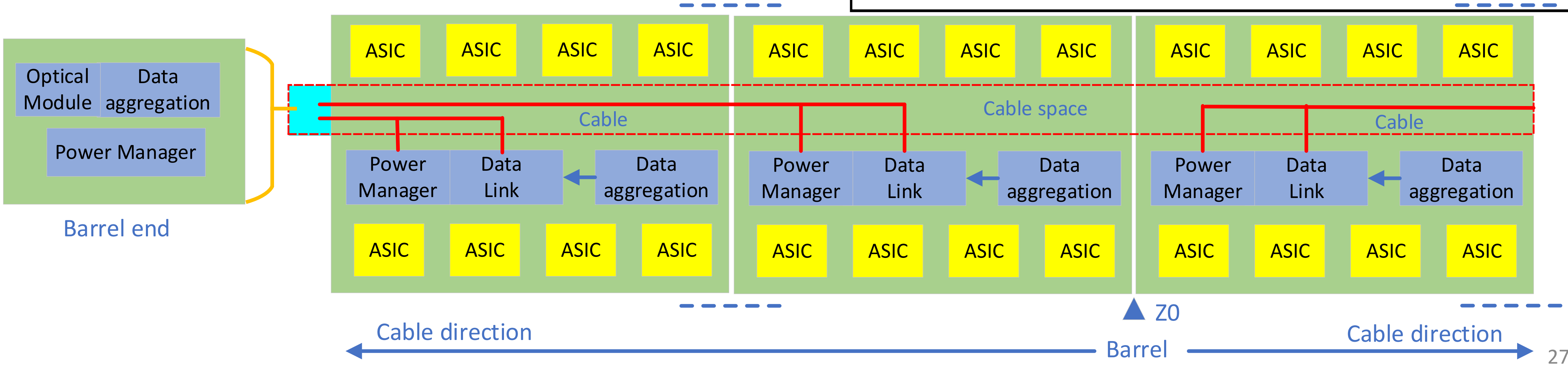
- Energy Measurement: ASIC for ECAL & HCAL
- Data transmission: common data platform （see electronics report）
- Trigger mode: FEE triggerless readout

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, Zhongtao Shen,

Mechanics:

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

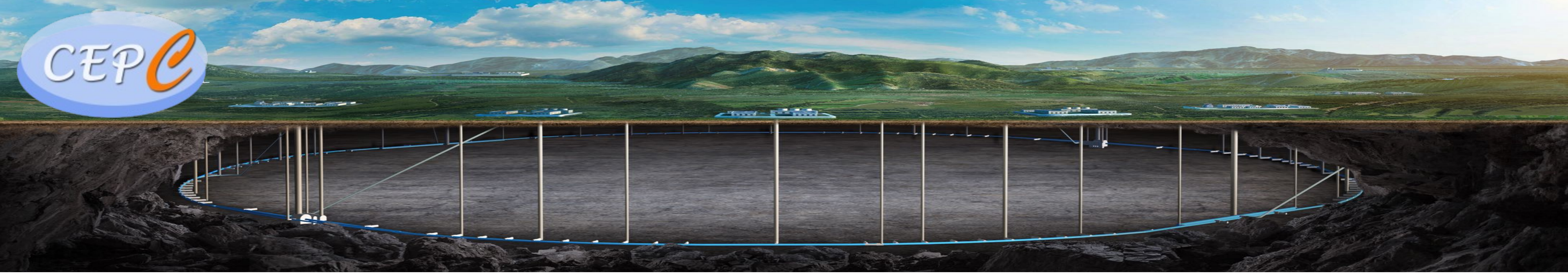
Institution: USTC, SJTU, IHEP

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!

Backup

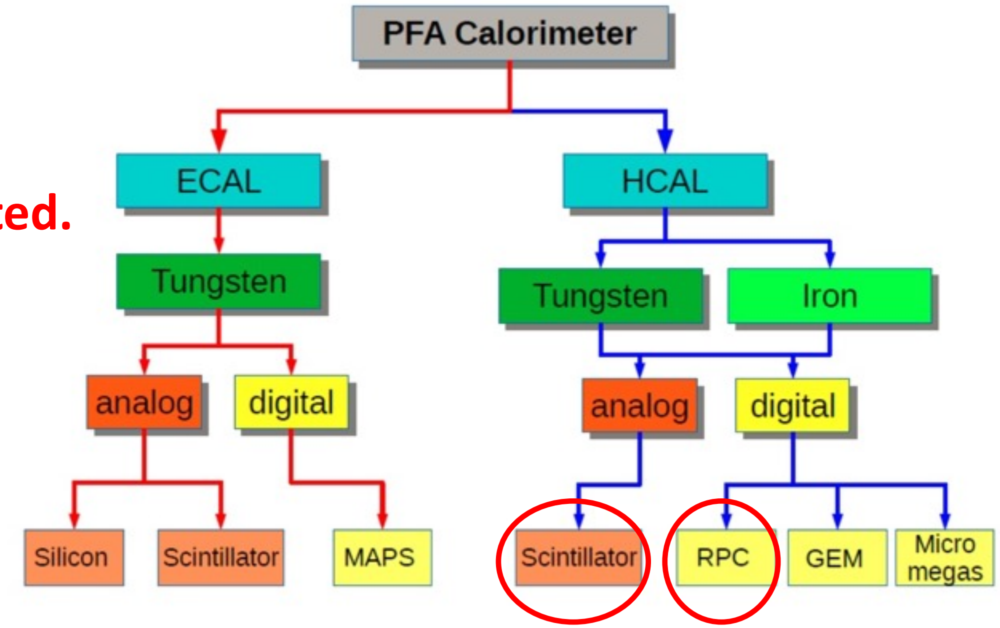
Introduction

- 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

Technology survey and our choices

- **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）**

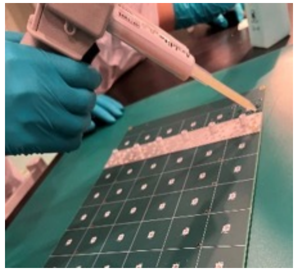


AHCAL-PS prototype assembling

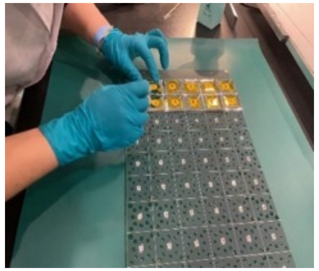
- Developed a procedure dedicated to fitting scintillator tiles onto the HBU boards

inspection

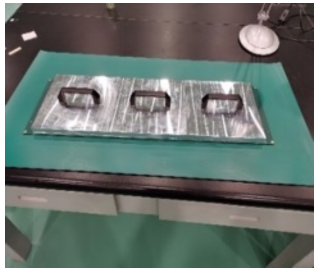
gluing



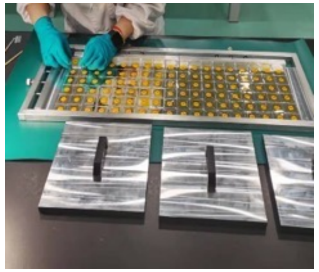
mounting

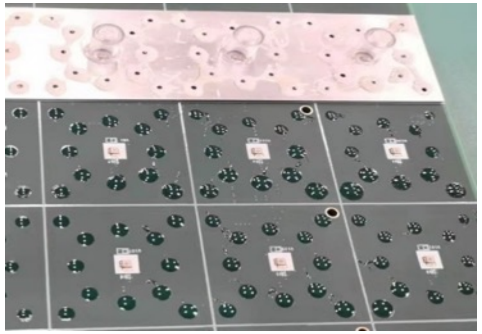


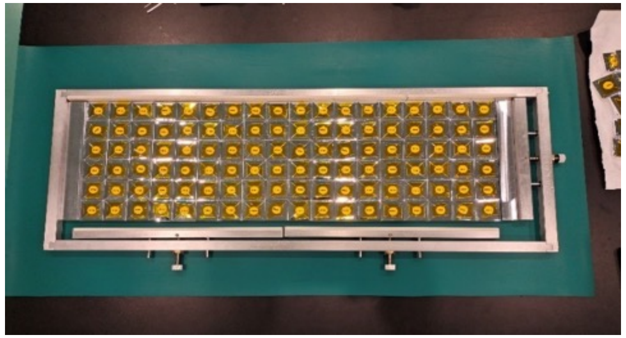
curing

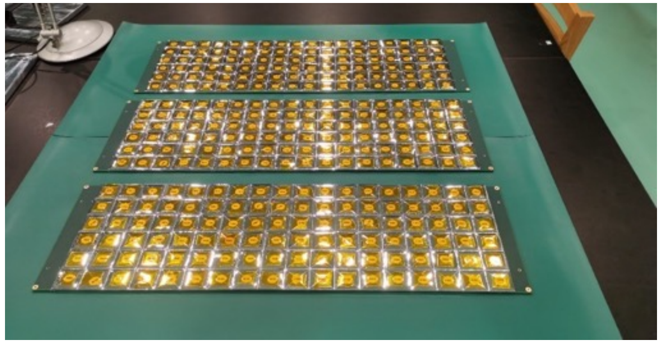


inspection

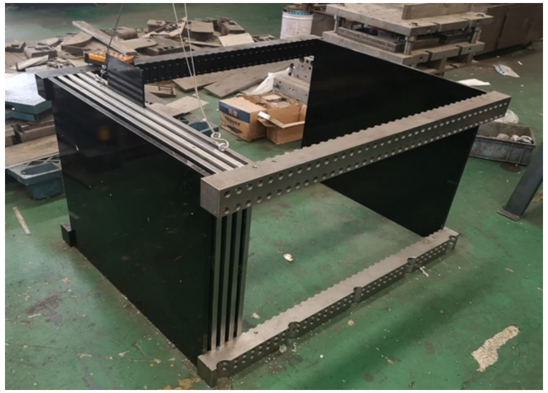








Absorber installation

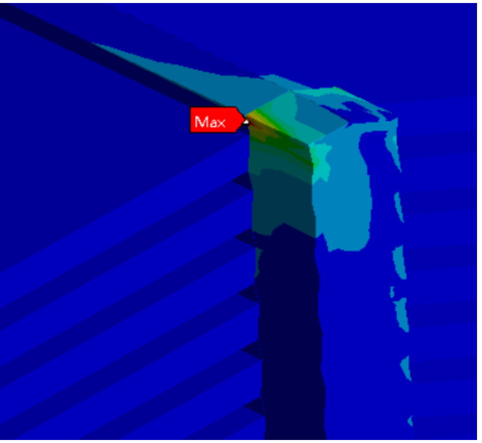


Actvie layer installation

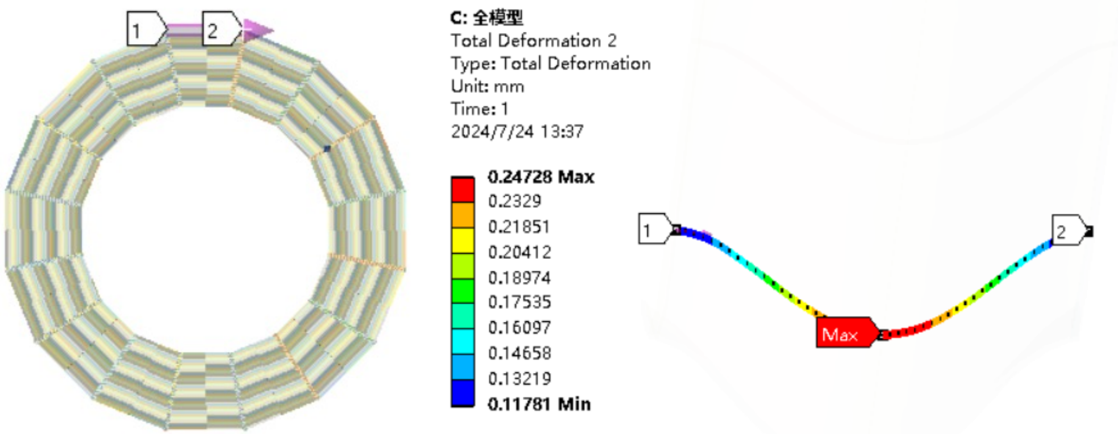
AHCAL-PS Beam tests at CERN

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

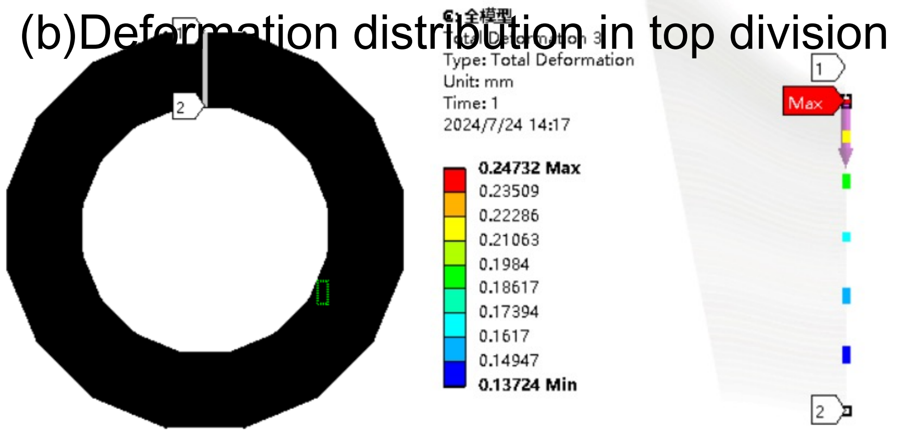
65 million events collected in total



Max. stress position



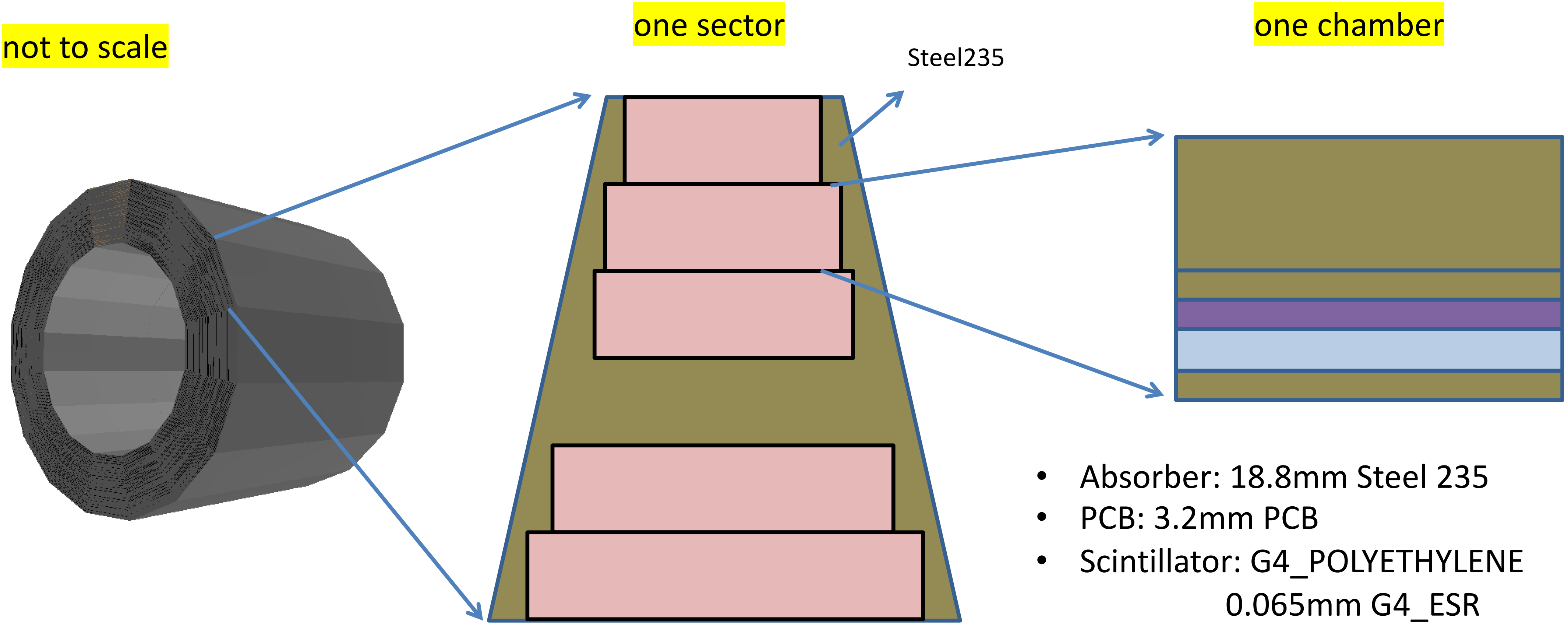
(a)Deformation distribution in top absorption layer



(b)Deformation distribution in top division

- 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

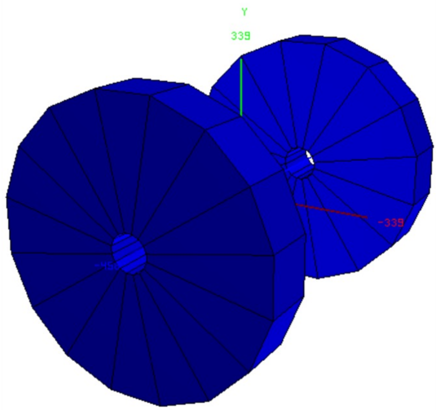


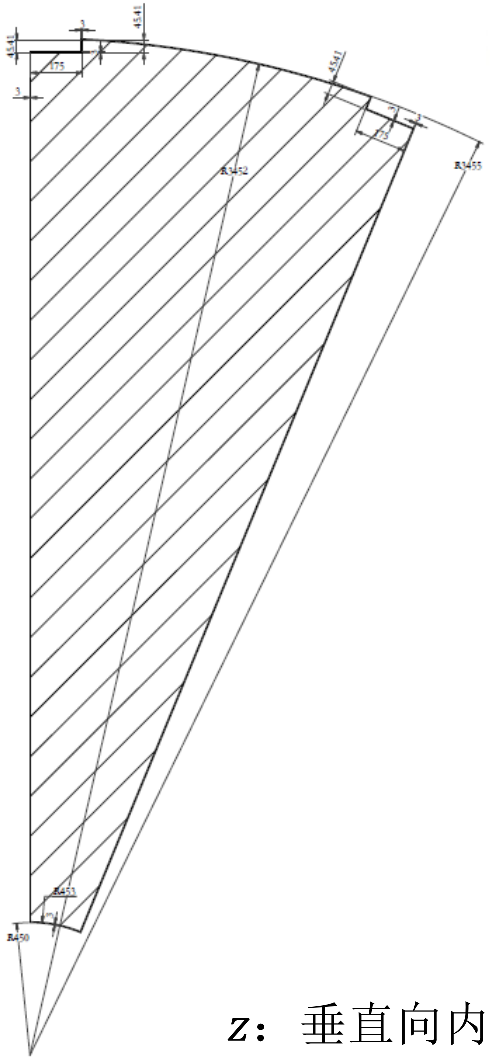
- Absorber: 18.8mm Steel 235
- PCB: 3.2mm PCB
- Scintillator: G4_POLYETHYLENE
  0.065mm G4_ESR
  - total distance in xy plane: 40.3mm
  - total thickness: 3.2mm
- Absorber: 2mm Steel235

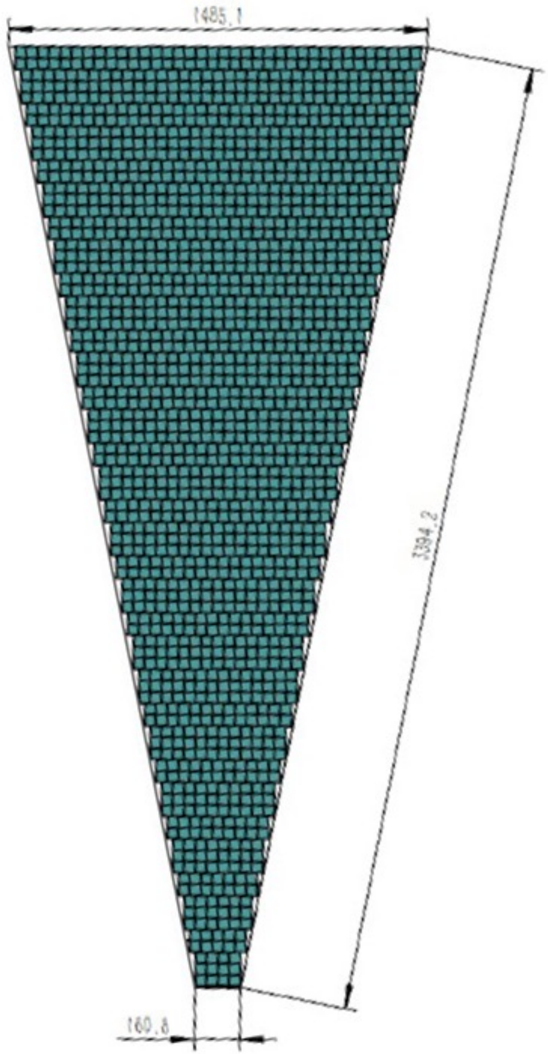
HCAL Endcap Set in CEPCSW

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





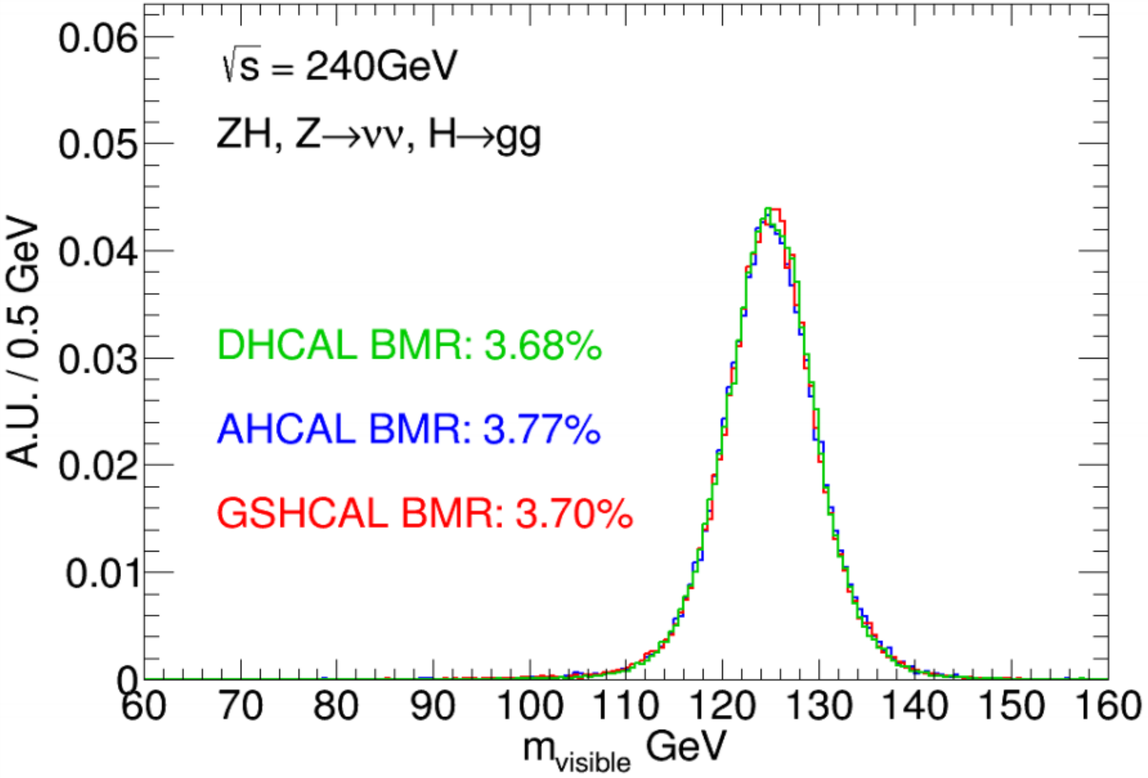


z： 垂直向内

（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



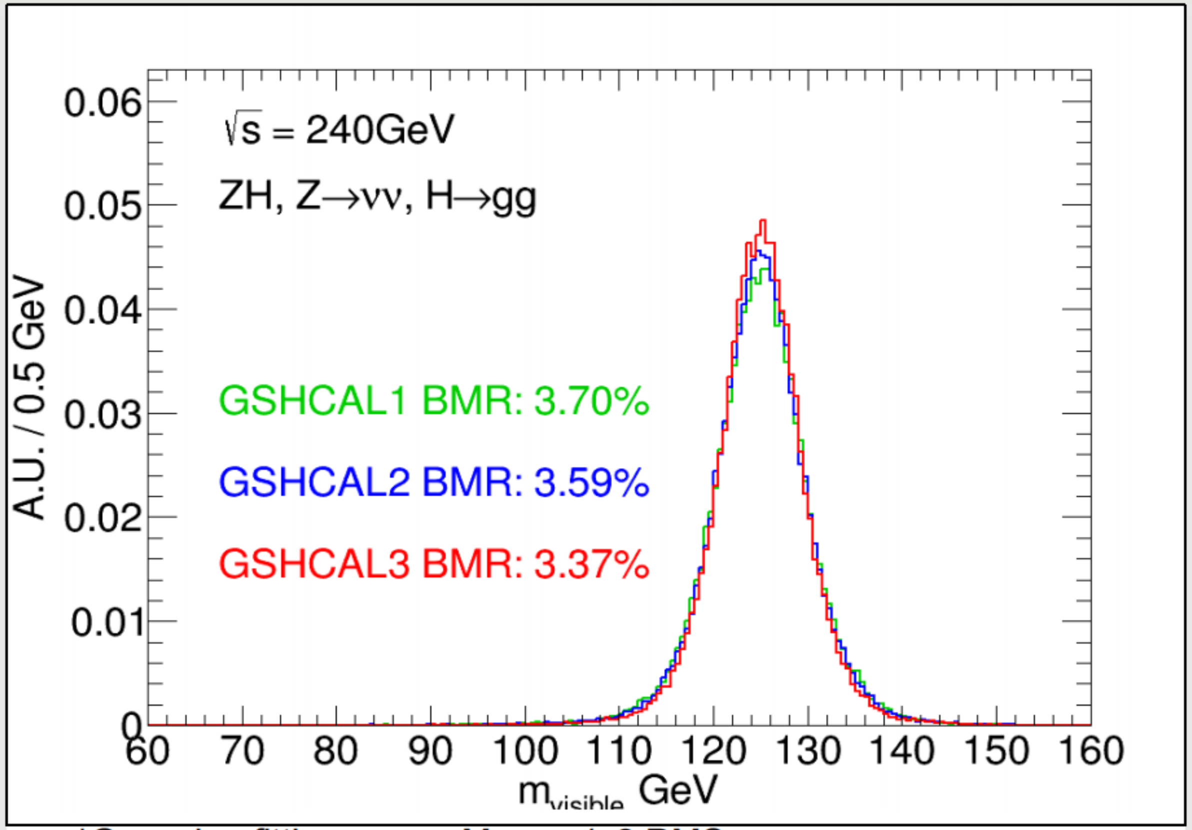
*Gaussian fitting range: Mean +/- 2 RMS

➢ 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

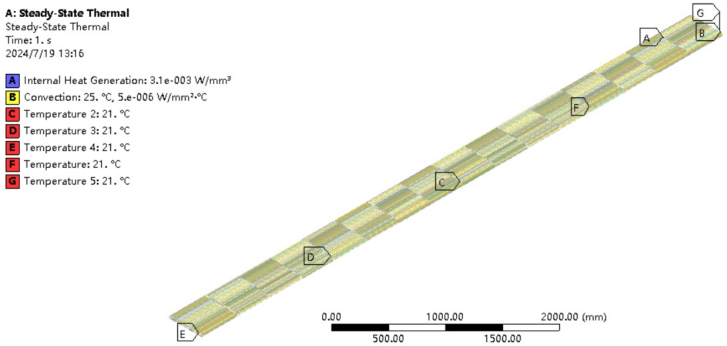
302/(5134*4.03)=1.4%

2.4*2*48/5134=4.5%

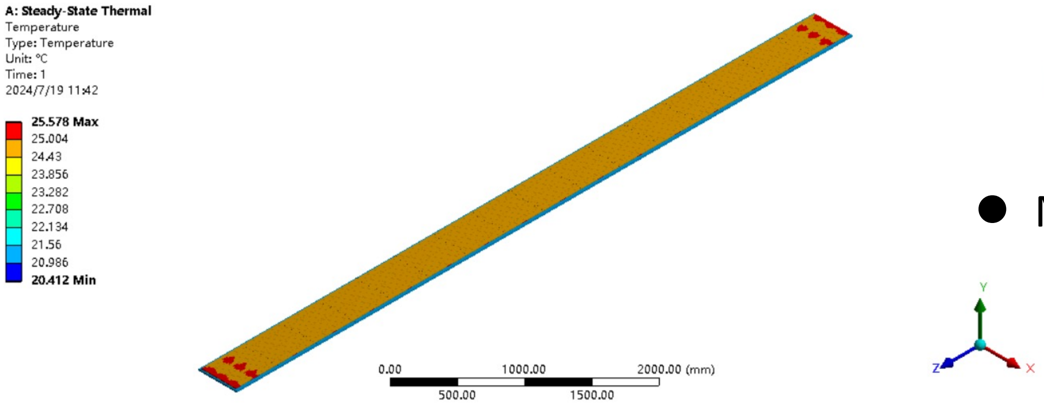
Barrel HCAL preliminary cooling design

From Yatian

Static temperature simulation result



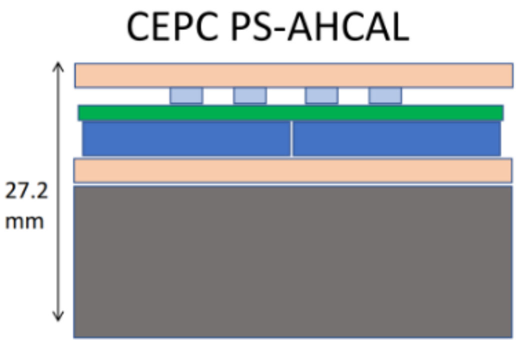
Boundary conditions



Temperature distribution of the model

- Max. temperature: **25.58℃**

Barrel HCAL preliminary mechanical design



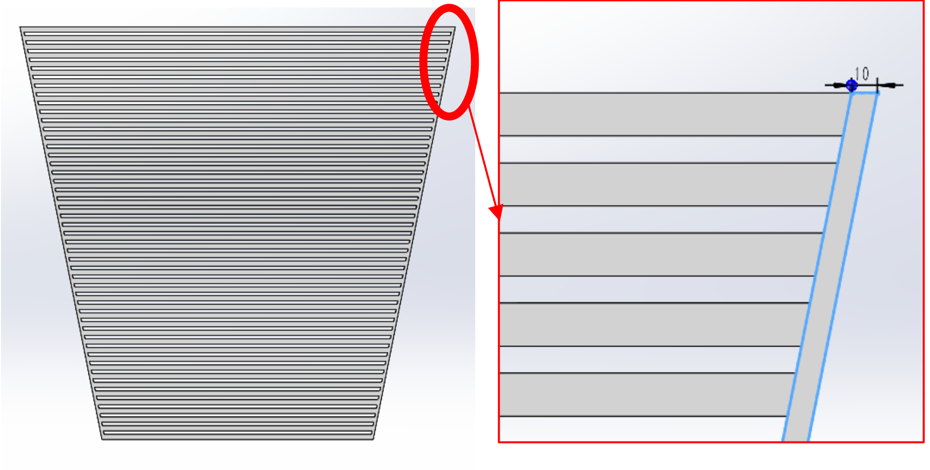
Based on PS-AHCAL

- Each PS is 4cm×4cm×3mm

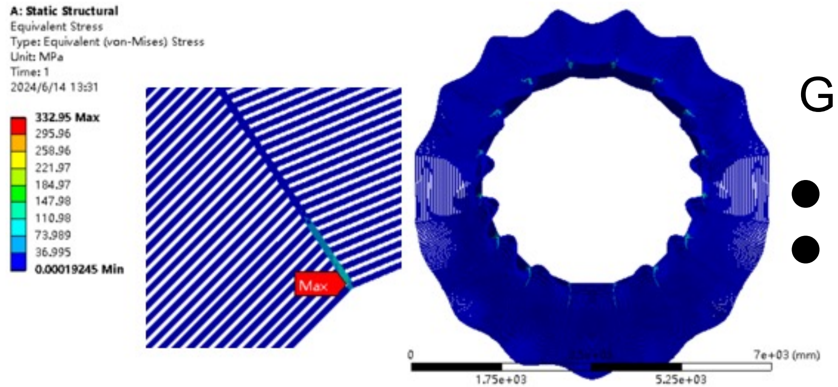
Statistics

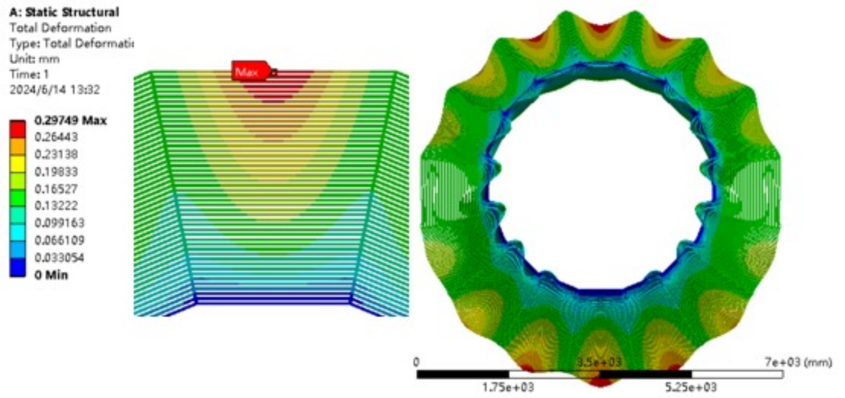
- Left width: 0.47mm to 38.5268mm, average is 19.78mm (can be used for reference thickness of side support)
- Possible support area ratio :Left width/ Layer width=1.78%
- Total SiPM for 1 division : 211232
- Total channel: **3.38 M**

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