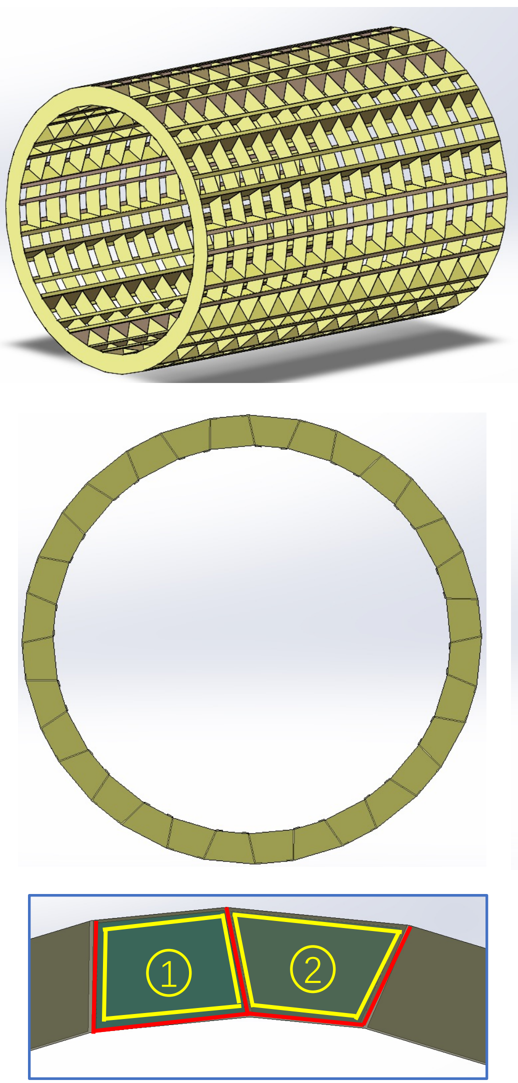
ECAL机械设计进展

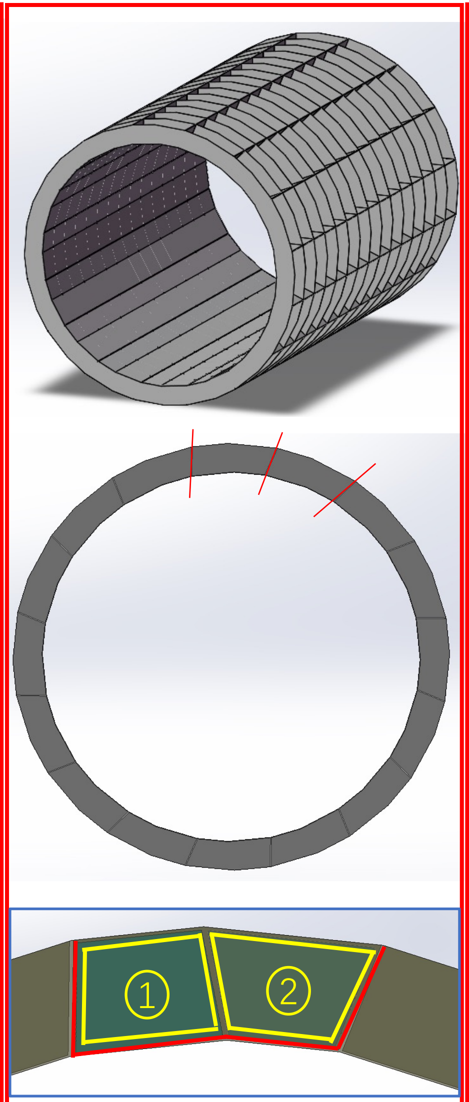
侯少静

10/15/2024

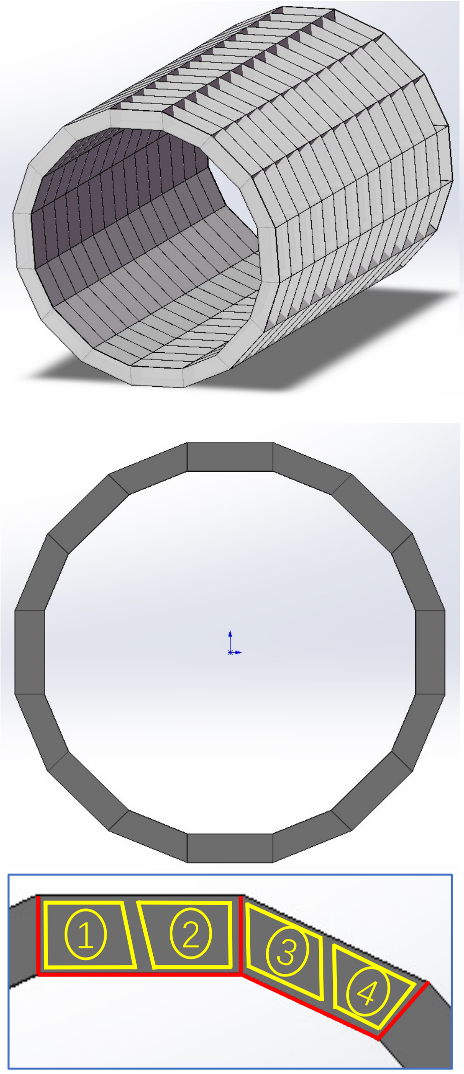
桶部优化设计方案



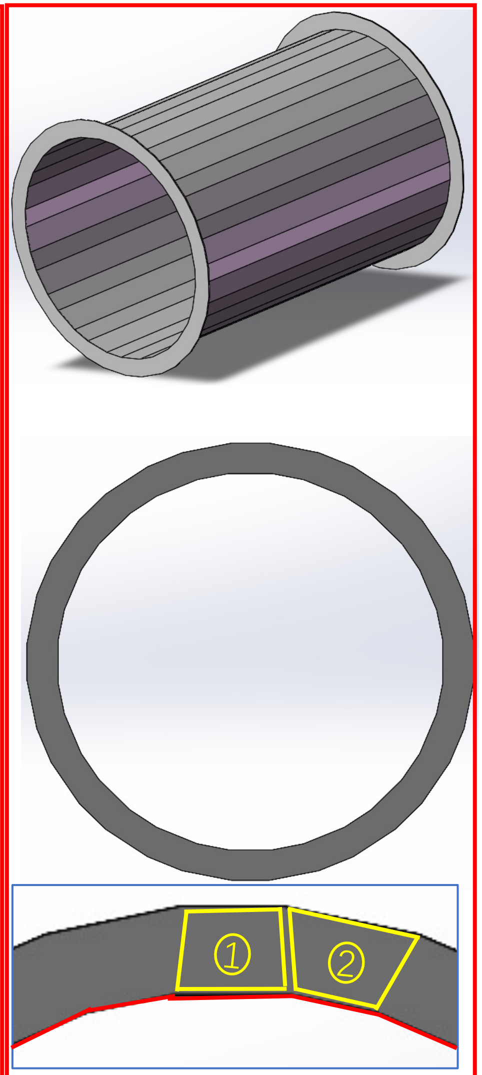
一：32边形正反梯形



二：32边形正反梯形
减Z向梁加内蒙皮

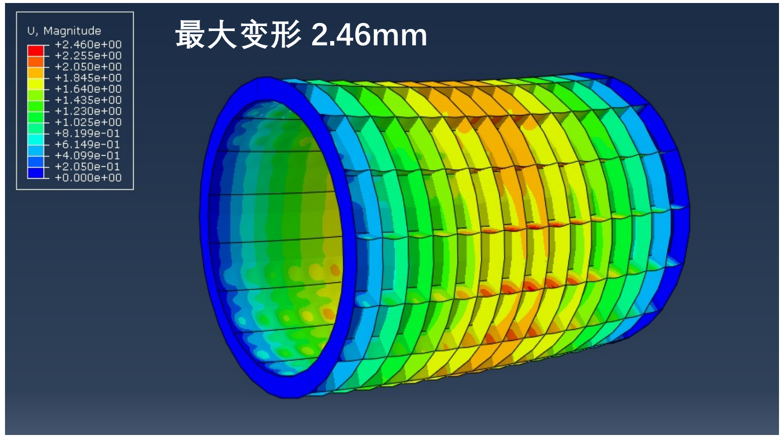


三：16边形方形+梯形
加内蒙皮

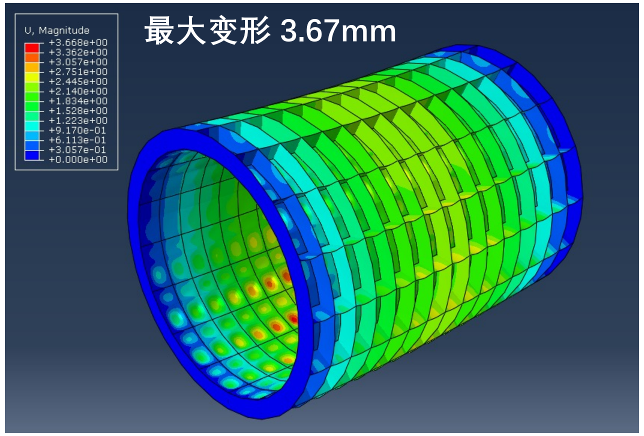


四：内筒+法兰

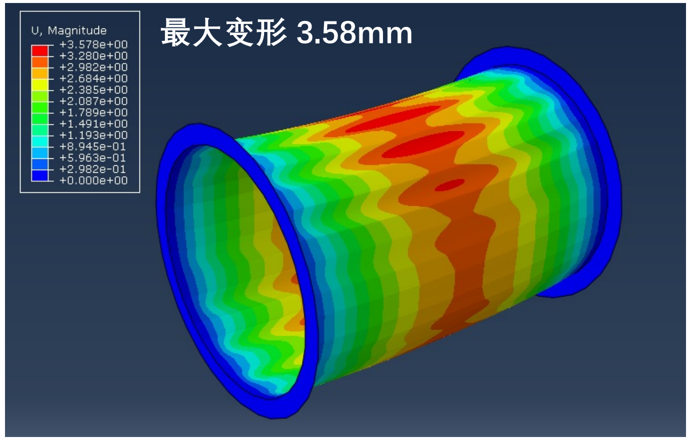
优化方案有限元结果



方案二
两端面20mm;
中间环向3mm;
Z向筋5mm;
内蒙皮5mm;
总重量：1220Kg



方案三
两端面20mm;
中间环向2.5mm;
Z向筋5mm;
内蒙皮3mm;
总重量：1050Kg

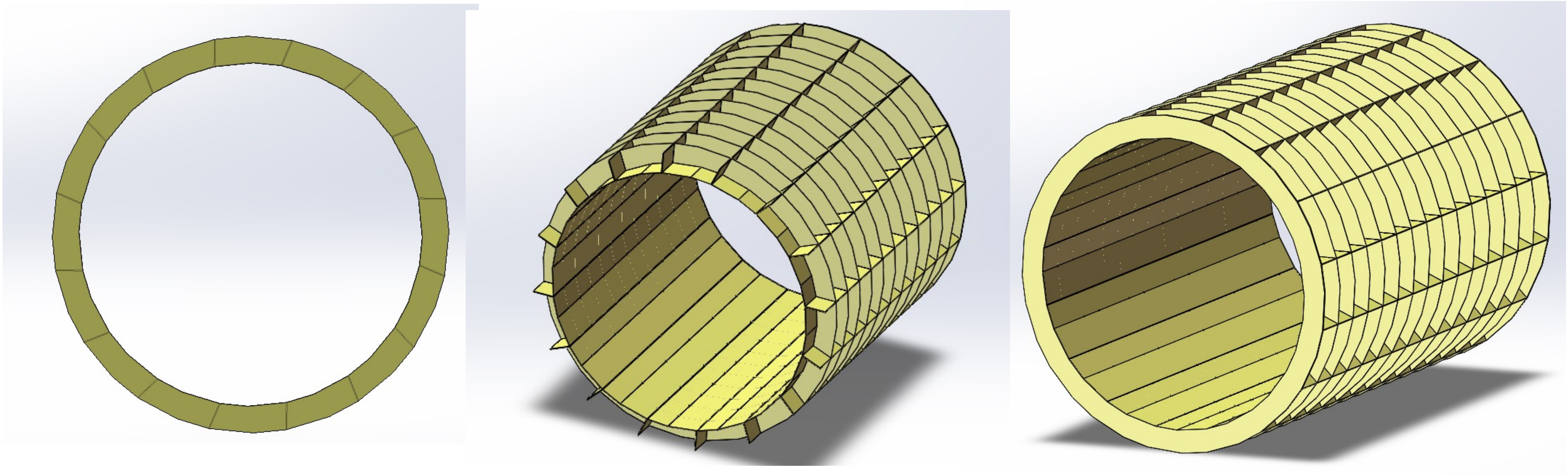


方案四
两端面20mm;
中间筒: 10mm;
总重量：1260Kg

方案	尺寸(左端面-中间环-Z向筋-右端面)	总重量/kg	支撑方式	最大变形/mm	
一	20mm-5-5-20mm，加筋50*5mm64条	1462	两端+底部	5.09	
二	20mm-3mm-5mm-20mm，内蒙皮5mm	1220	两端	2.46	TDR
	20mm-3mm-5mm-20mm，内蒙皮3mm	1006	两端	3.26	
三	20mm-3mm-3mm-20mm，内蒙皮5mm	1332	两端	2.64	
	20mm-2.5mm-5mm-20mm，内蒙皮5mm	1274	两端	1.94	
	20mm-2.5mm-5mm-20mm，内蒙皮3mm	1050	两端	3.67	
四	20mm-20mm，内蒙皮10mm	1260	两端	3.58	

方案二、三、四与方案一相比，结构满足模块全部从外部组装，增加内部连续筒，整体刚度增加，取消底部支撑，只在两端支撑的情况下，最大变形减小。

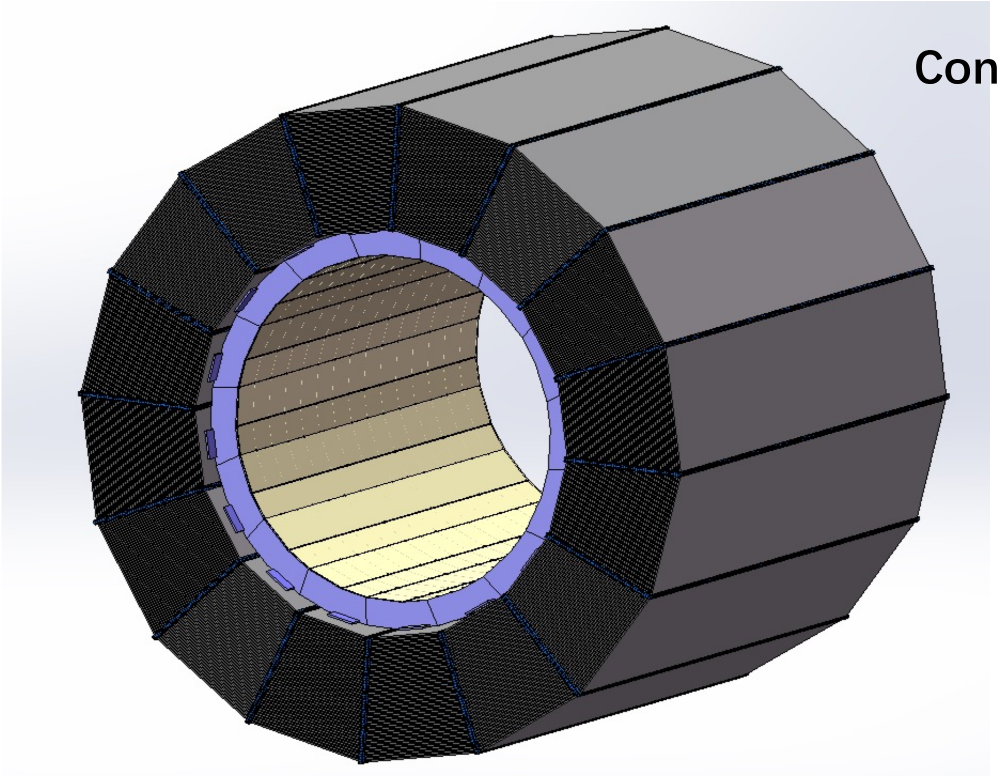
Main structure of ECAL



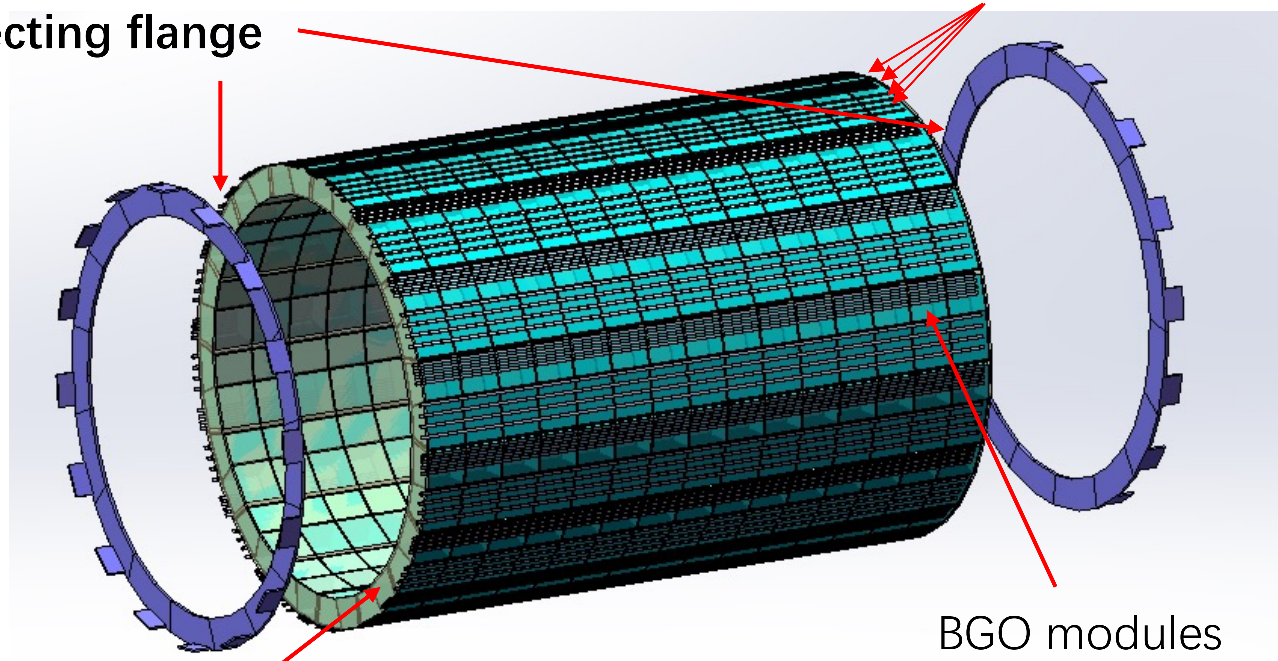
The main structure of ECAL is made of **carbon fiber reinforced epoxy (CFRP).** The barrel is divided into 16 parts in the ring direction and 15 parts in the Z direction, and each cell has a BGO module.

The thickness of the ring is 3mm , and Z-beam is 5mm. the thickness of inner skin is 5mm.The weight of the main structure is 1220 kg.

Mechanical structure of ECAL

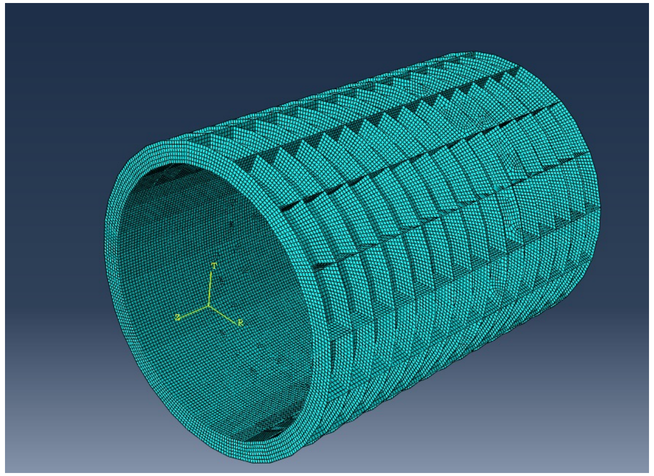


HCAL+ ECAL

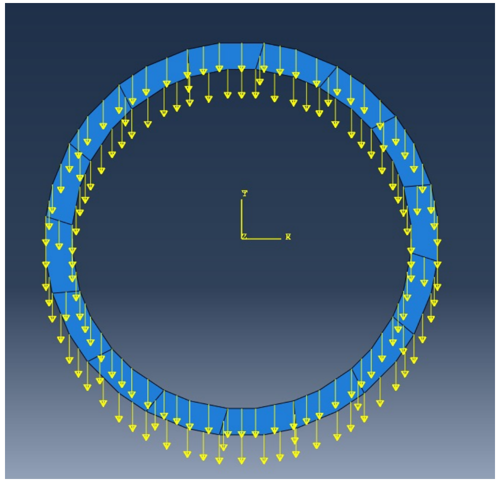


ECAL

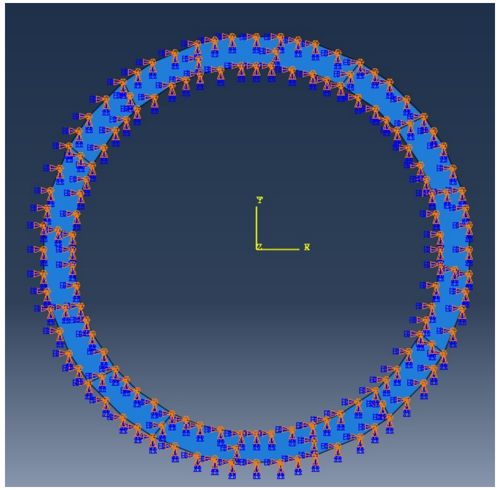
FEA of Main structure



Elements (type: shell)



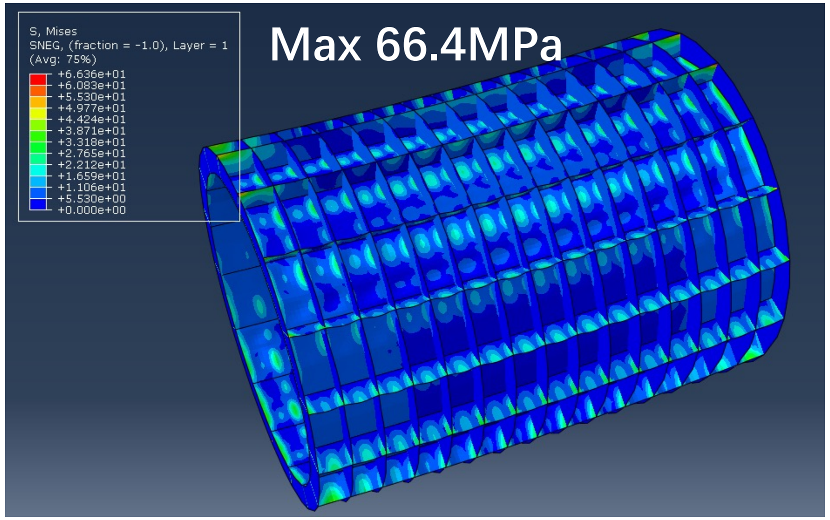
Loads (Gravity+150t static load)



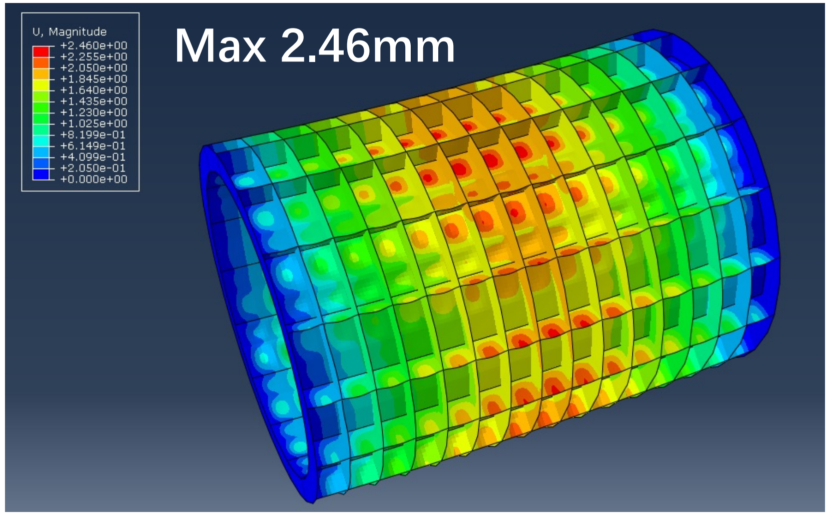
Constraint (ends fixed)

Material :T700 reinforced epoxy resin.

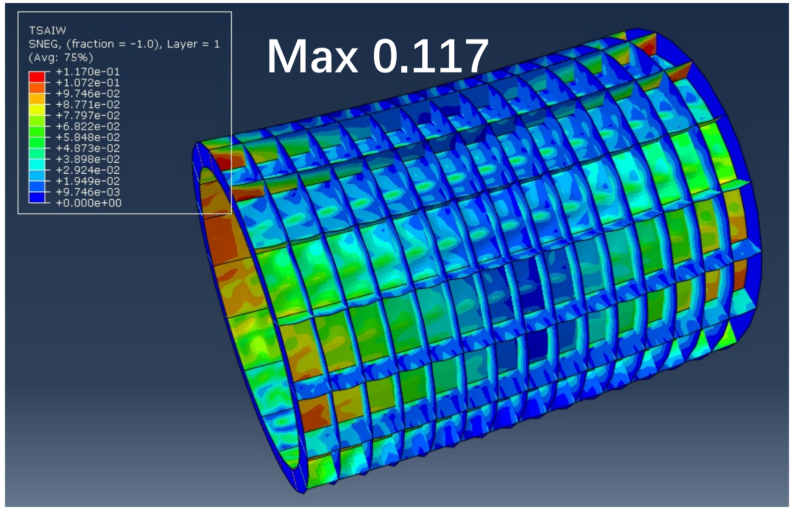
When **TSAIW=1**, material begins to fail. According to the results **0.117**, **safety factor** of this structure is 1/0.117=8.5.



Mises stress



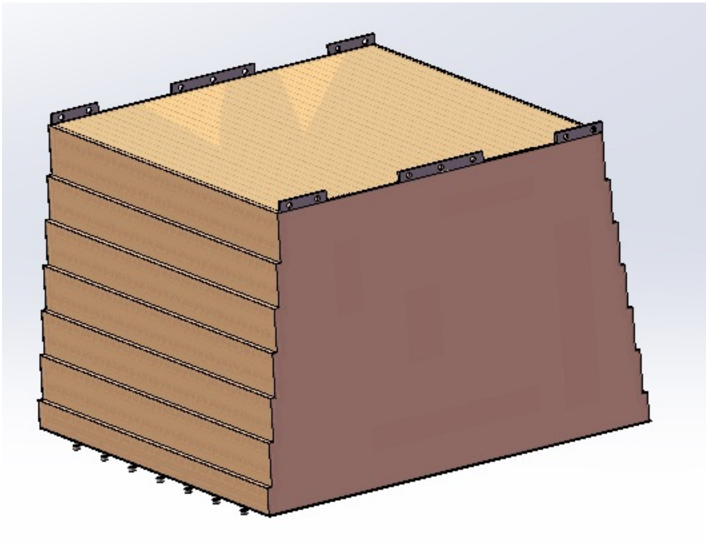
Deformation

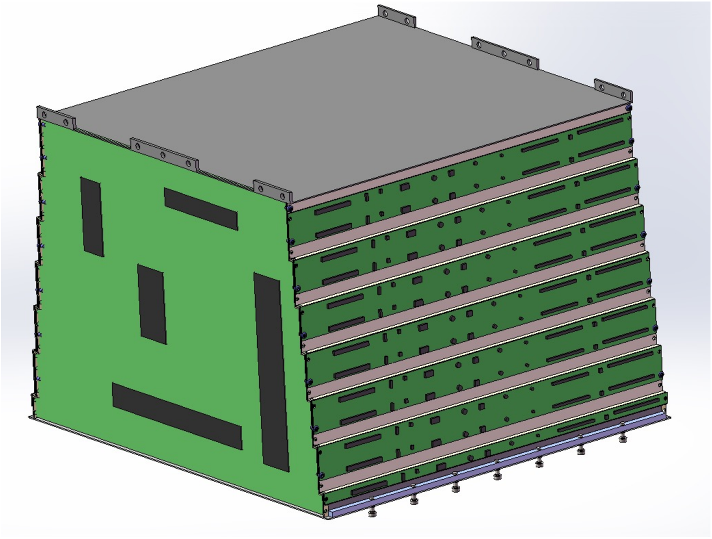


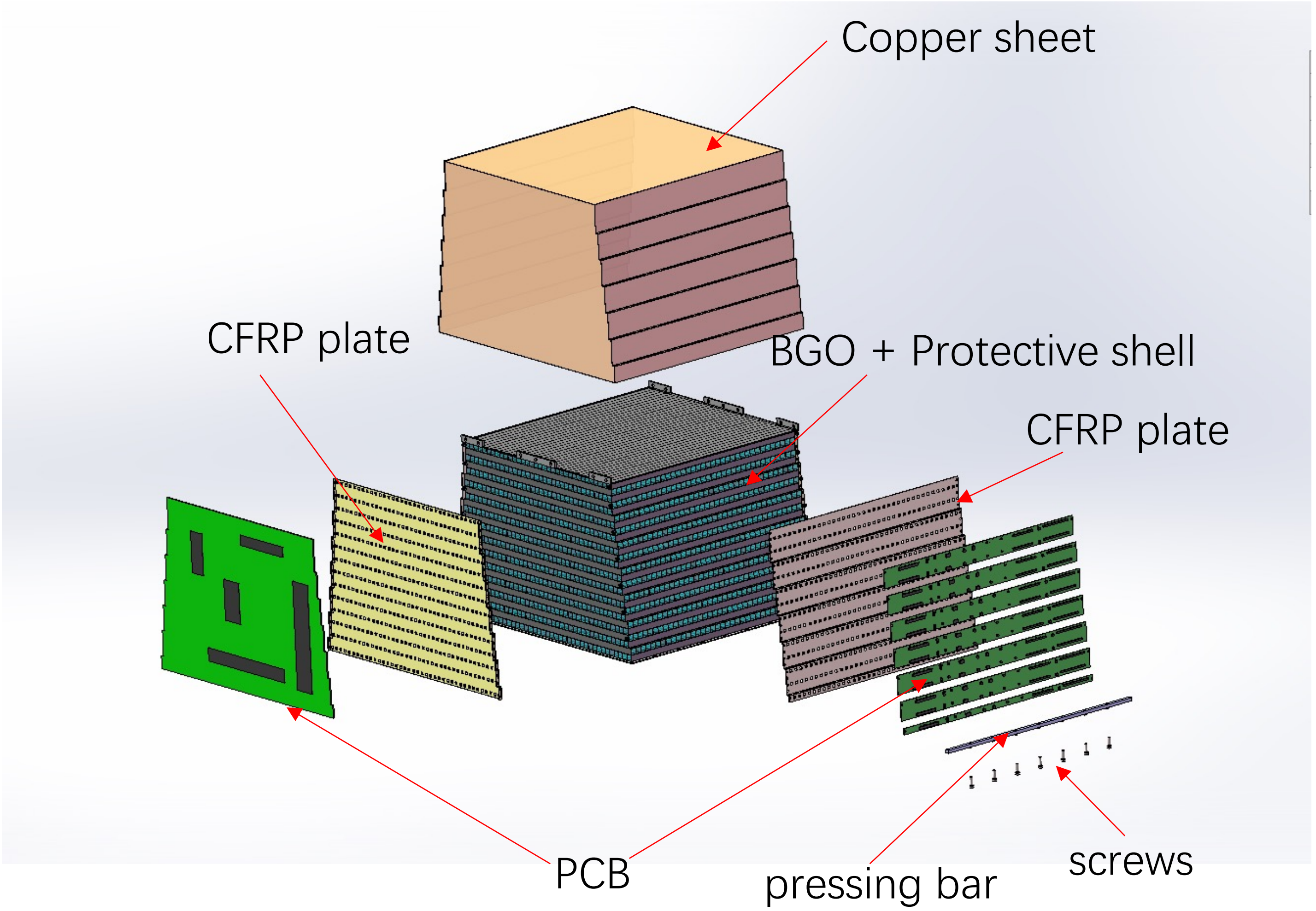
TSAIW

(Failure parameters of composite materials)

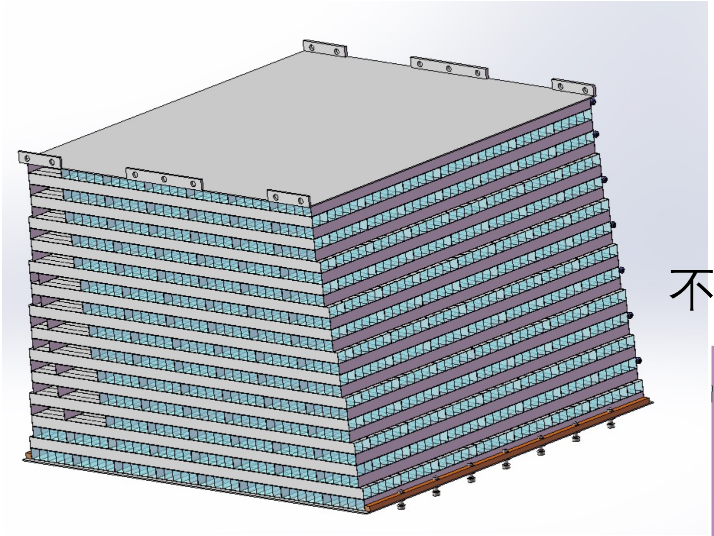
Structure of BGO module



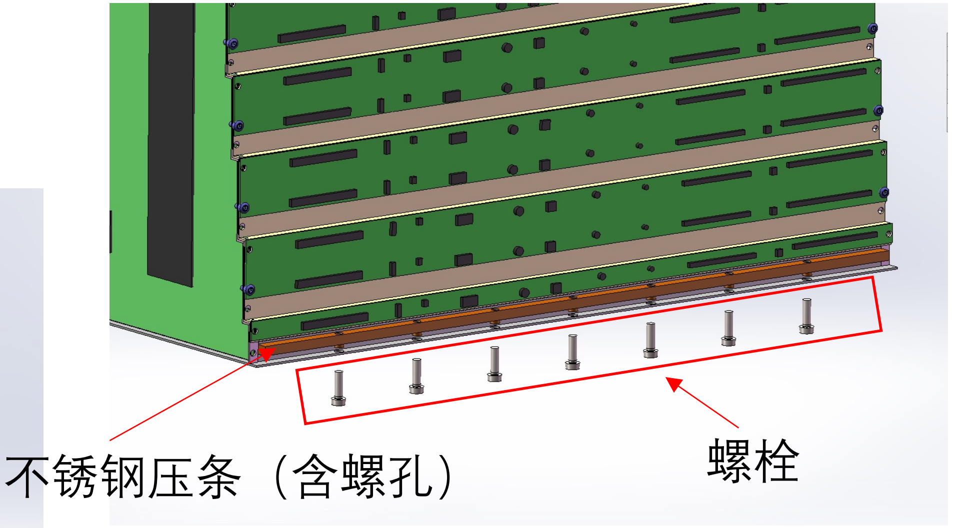


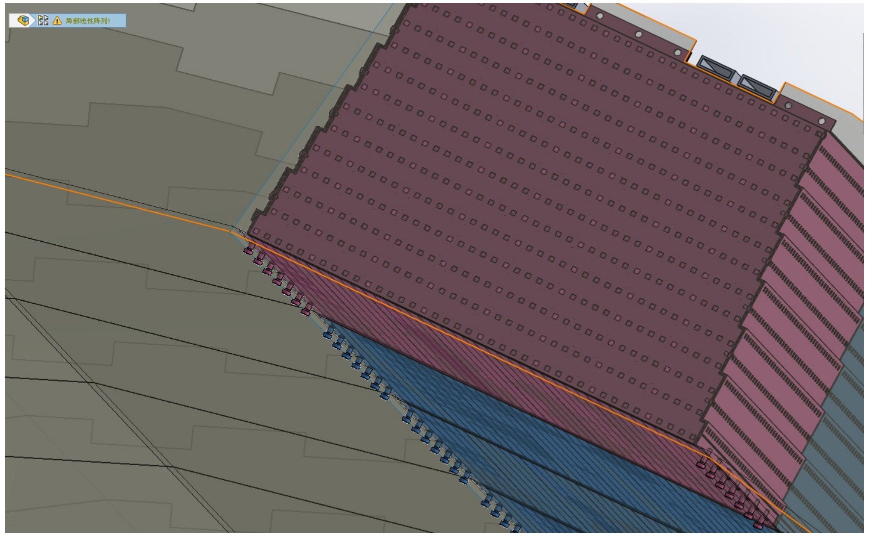


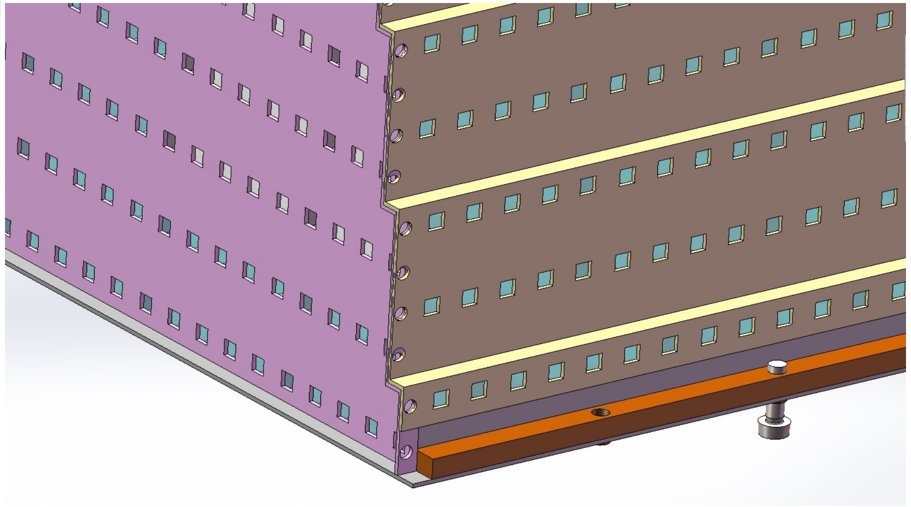
模块设计细节



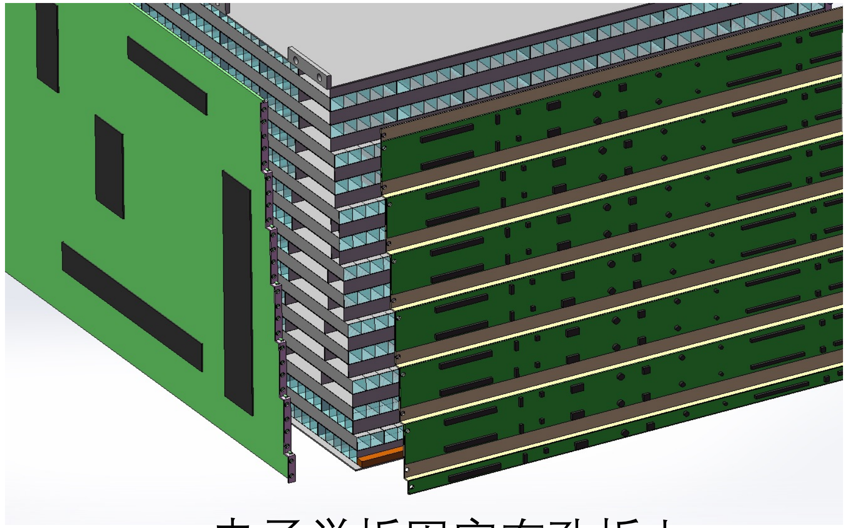
上下底板：1mm
腔体尺寸：10mm*50mm(最大)
腔体壁厚：0.2mm
模块重量：279kg





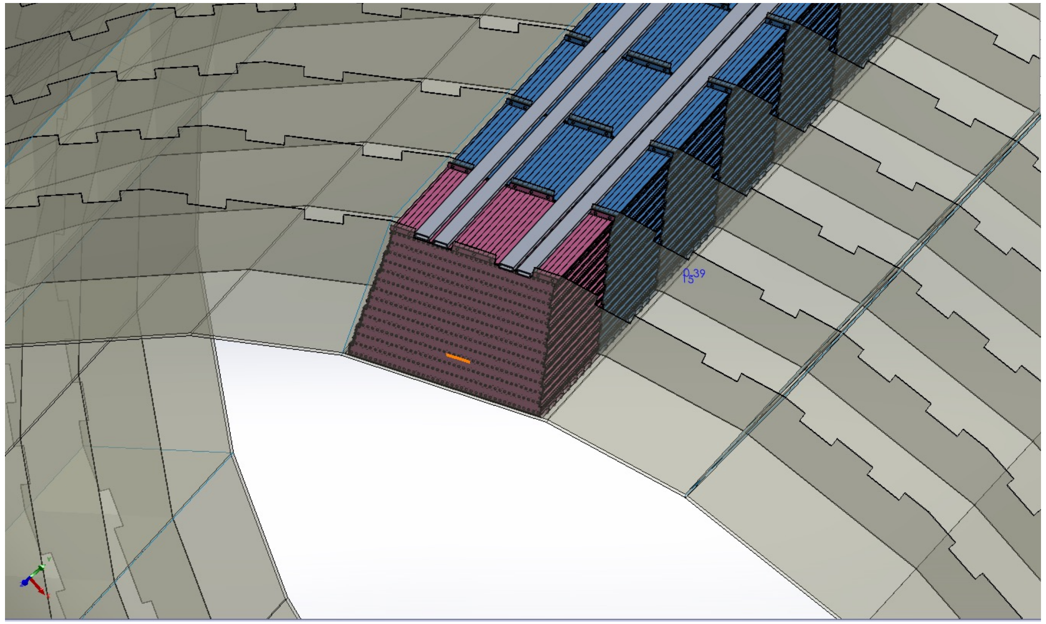


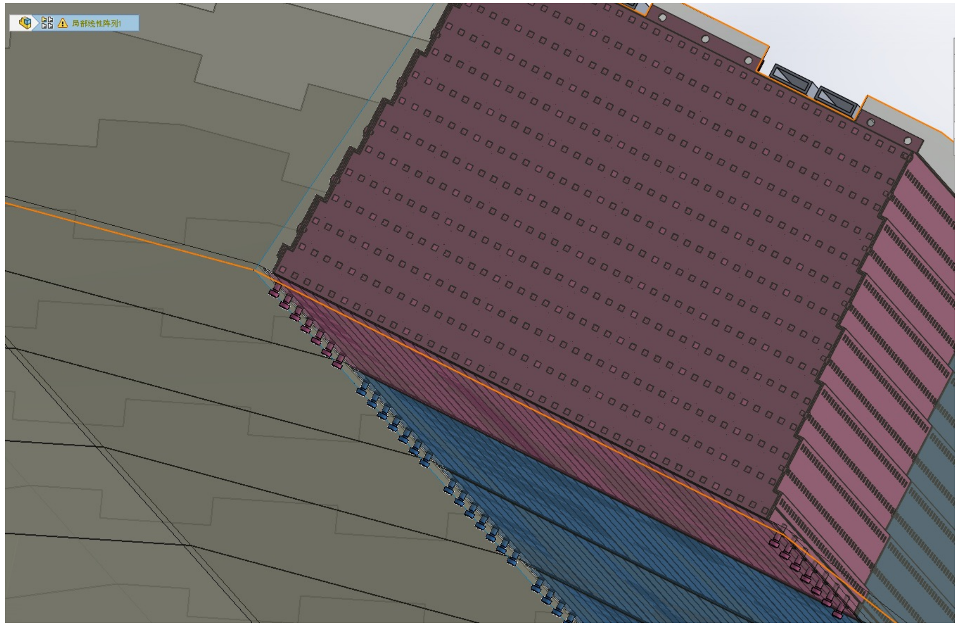
四周碳纤维孔板



电子学板固定在孔板上

Module fixation





Each module fixed into the main structure by bottom bolts. Four heat dissipation pipes installed at the top of each row of modules.

BGO晶体抗弯强度分析

JOURNAL OF MATERIALS SCIENCE LETTERS 4 (1985) 779–782

Monocrystalline bismuth germanate $Bi_4Ge_3O_{12}$ (BGO) recent results on mechanical properties

MICHEL LEBEAU
LAPP, Laboratoire d'Annecy-le-Vieux de Physique des Particules, 74019 Annecy-le-Vieux, Cedex, France

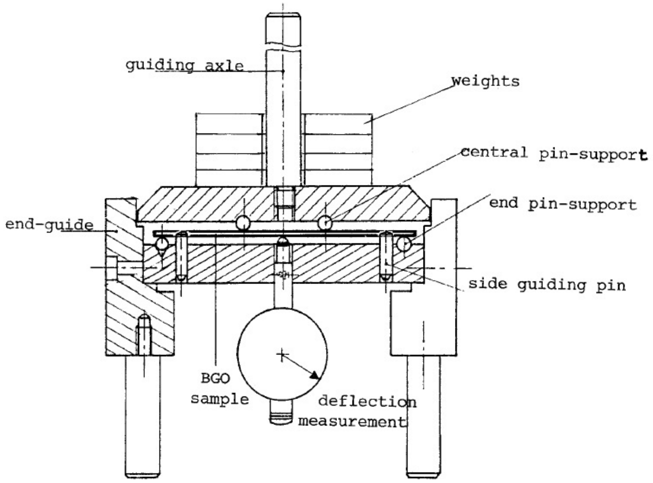


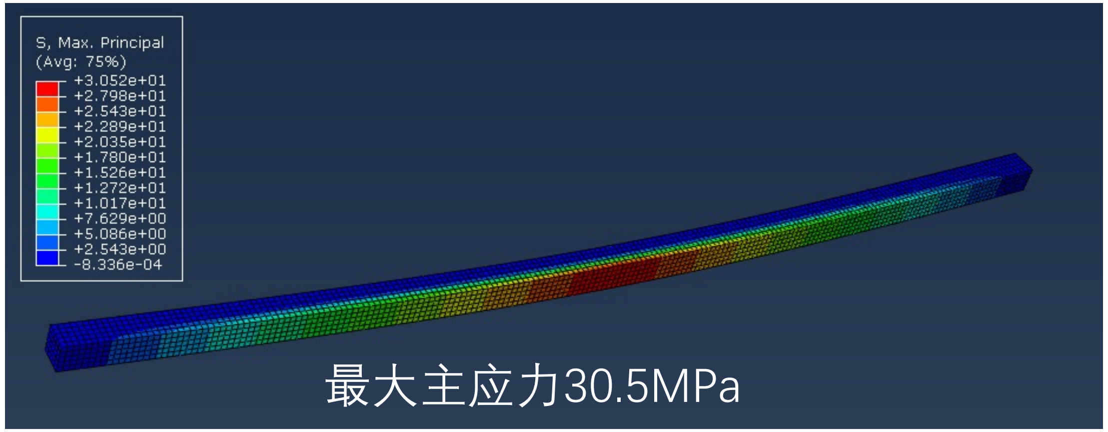
Figure 2 Four-point bending test set-up.

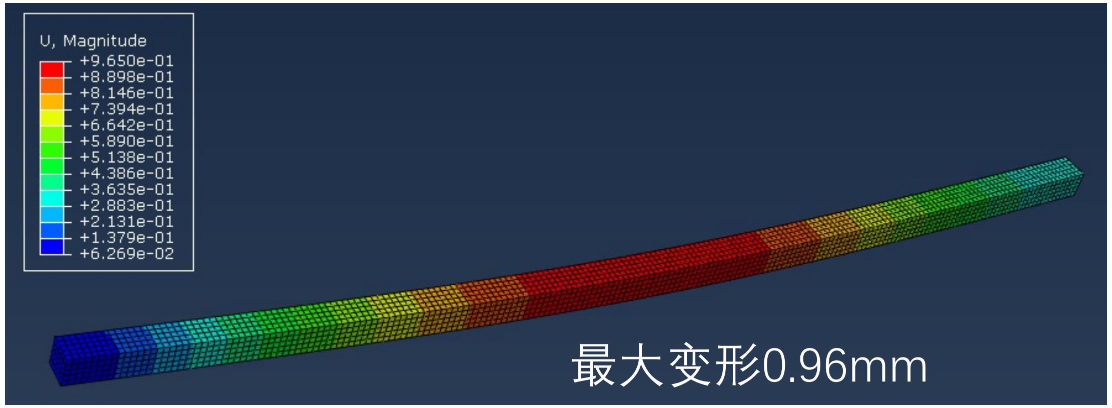
All the tests are recorded in Table II.

TABLE II Flexural tests on $Bi_4Ge_3O_{12}$

Test number	σ_R (hbar)	Loaded volume (mm^3)	Loading time (h)
(a) Four-point bending tests			
1	4.05	816	
2	4.4	816	
3	4.0	816	
4	2.7	816	
5	2.97	816	0.5
6	2.90	816	16
7	3.0	1360	
8	2.11	1360	
9	3.43*	1360	
10	3.06	1360	11

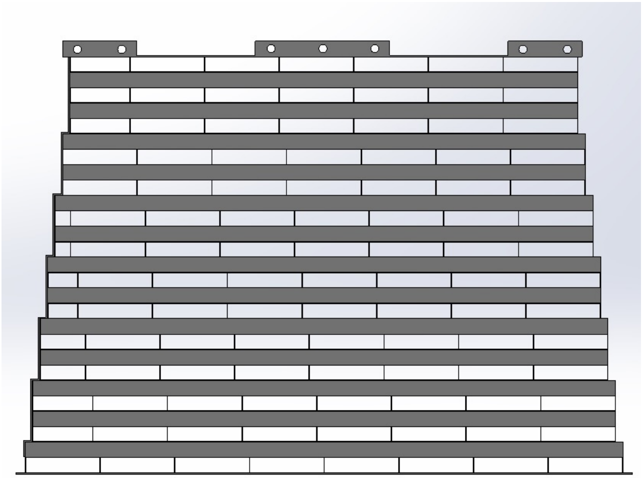
根据文献，BGO的抗弯强度在30-40MPa



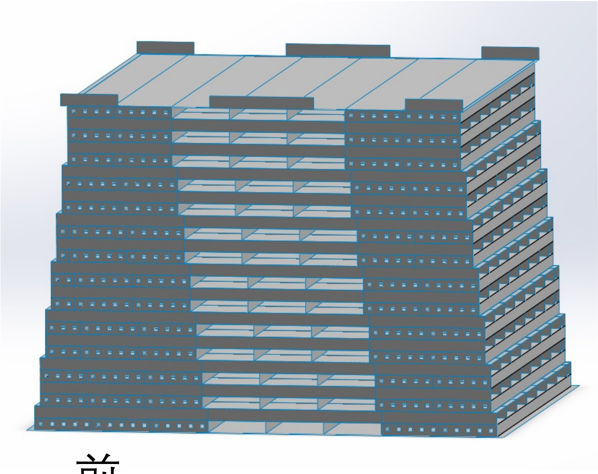


通过模拟，尺寸为10*10*400mm的BGO晶体条，弯曲应力约30MPa时,最大变形0.96mm。
以此作为模块保护壳设计依据。

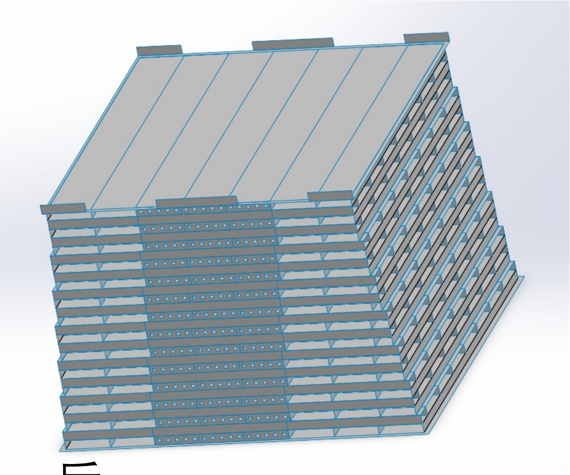
模块优化及强度计算



第一版



前

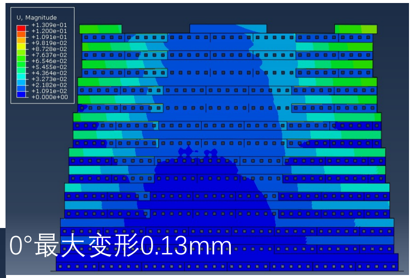


后

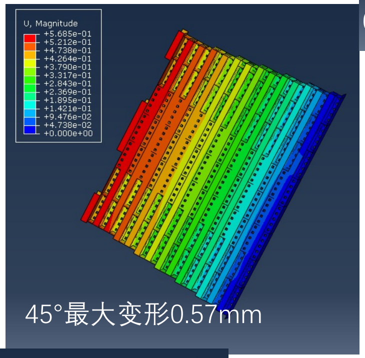
第二版

优化位置：开口方向在Z向的腔体一侧加端盖，
增加模块高度方向刚度。

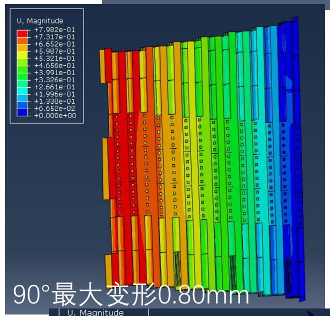
模块不同安装角度变形分析



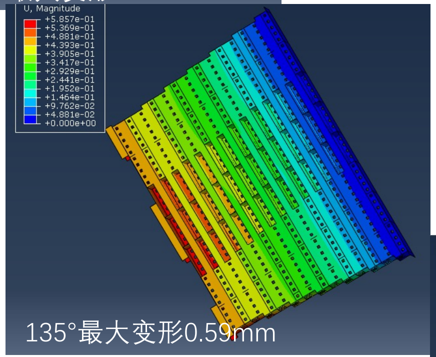
0°最大变形0.13mm



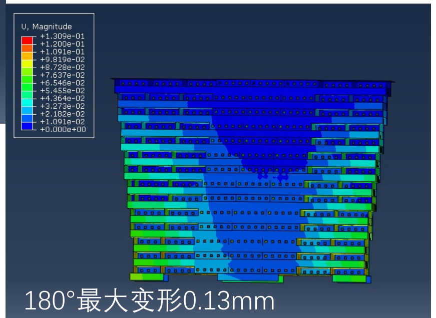
45°最大变形0.57mm



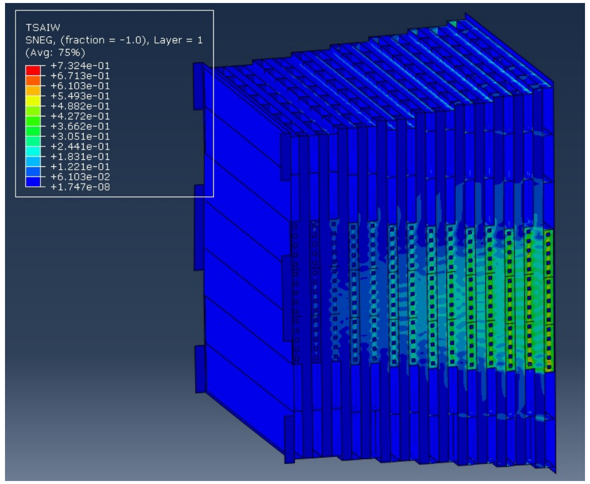
90°最大变形0.80mm



135°最大变形0.59mm



180°最大变形0.13mm

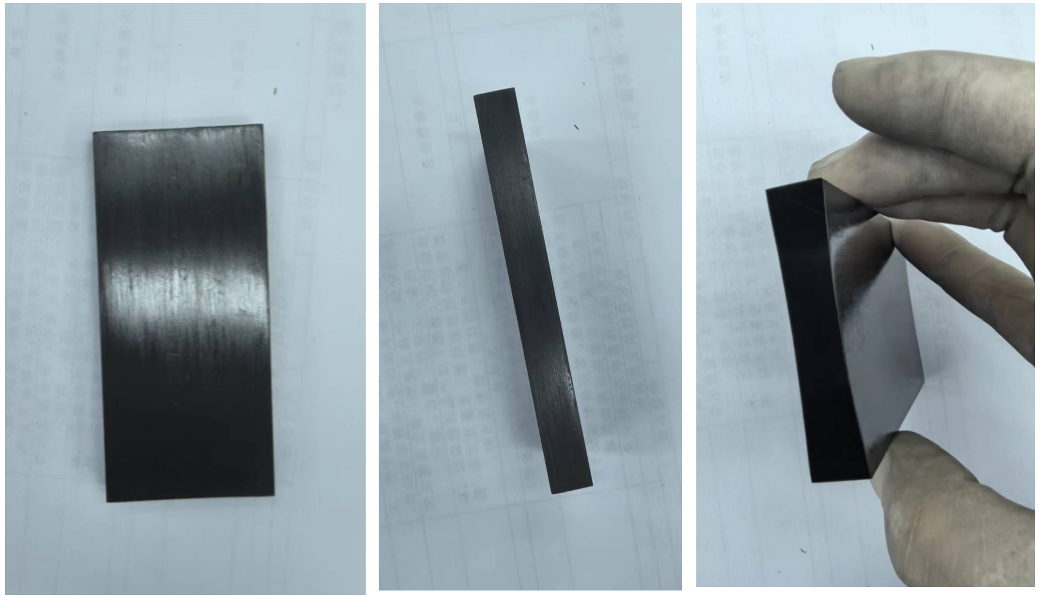


90°TSAIW最大0.73

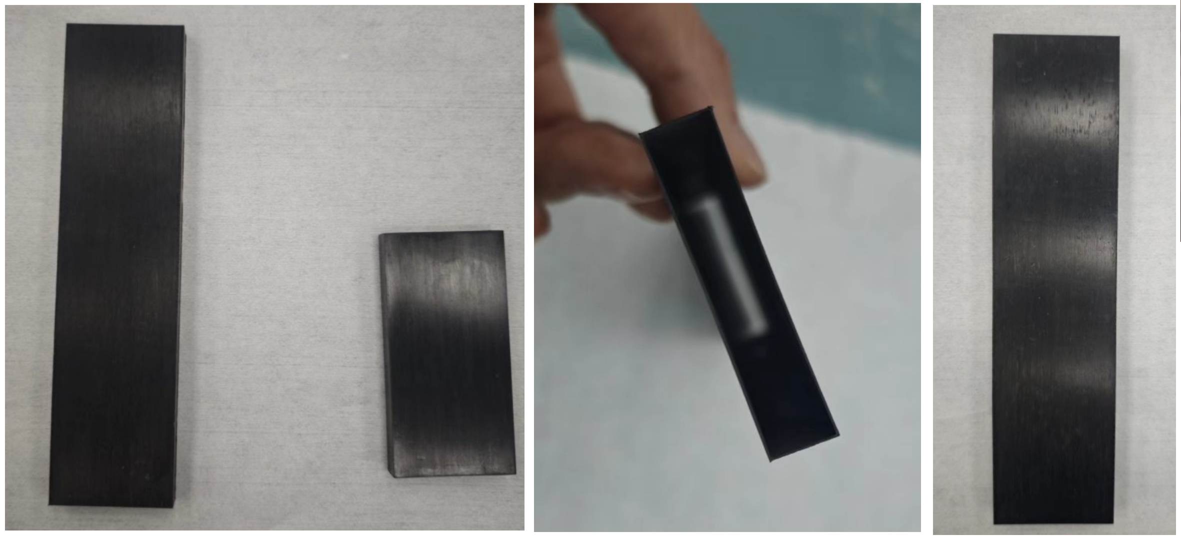
模块整体最大变形从0.13-0.8mm，此为27层累积变形，结合晶体弯曲变形分析，认为模块结构足以保护晶体不被损坏。

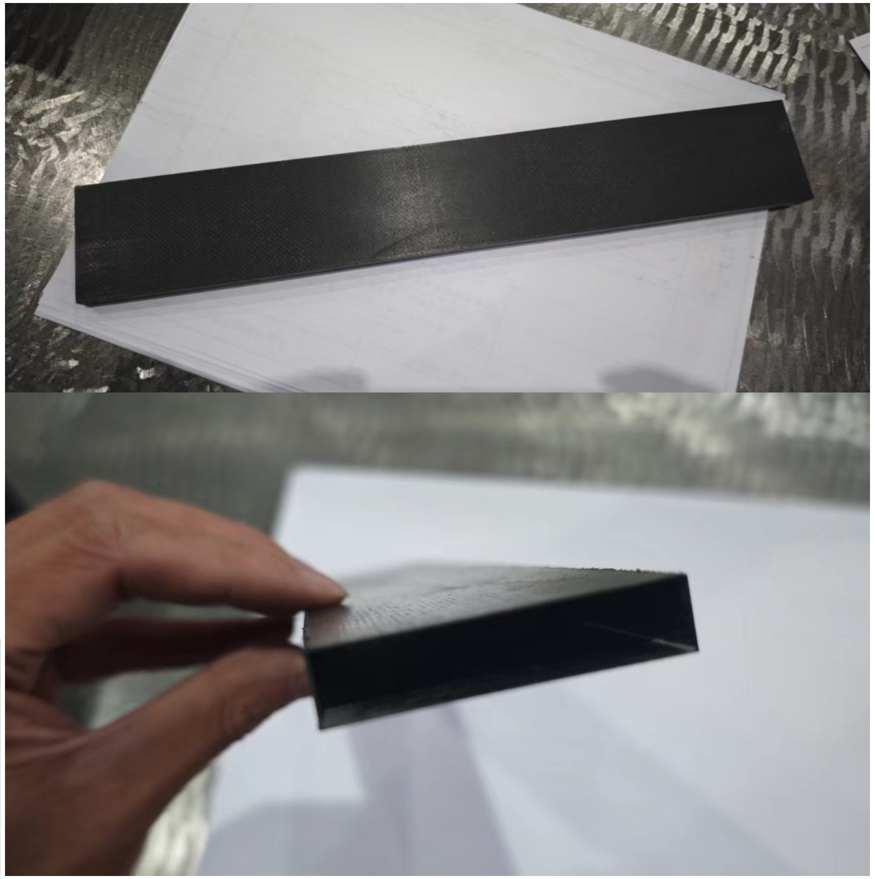
模块试制

预浸
0.2mm壁厚
100mm长



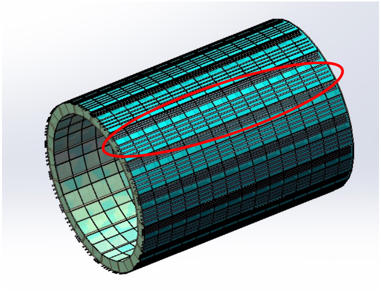
预浸
0.3mm壁厚
200mm长





碳布
0.37-0.4mm壁厚
331mm长

Cooling system of ECAL



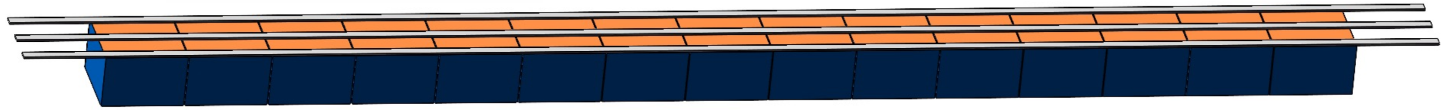
Cooling system for 1/32 barrel

42W for each module（**15mW/channel**）

Cooling medium: 10C° water

original version

inlet



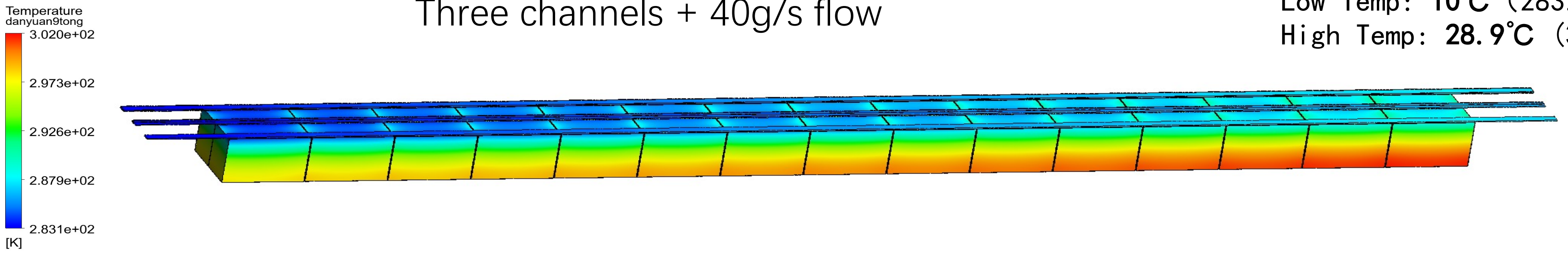
outlet

Copper sheet:**0.5mm**

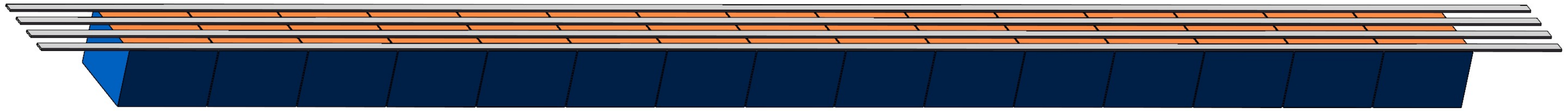
Low Temp: **10℃** (283.15K)

High Temp: **28.9℃** (302.014K)

Three channels + 40g/s flow



Optimal version



Copper sheet:**1mm**

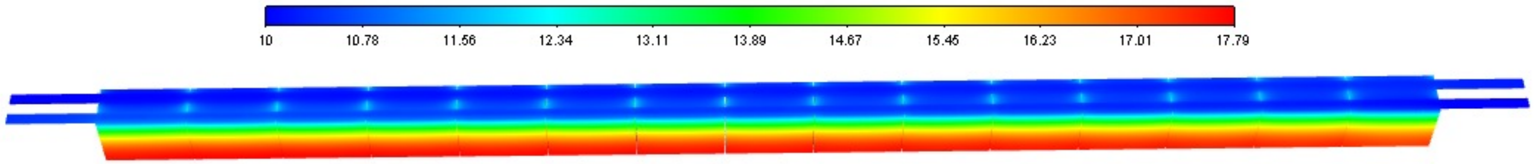
Low Temp: **10℃**

High Temp: **17.8℃**

Four channels + 100g/s flow

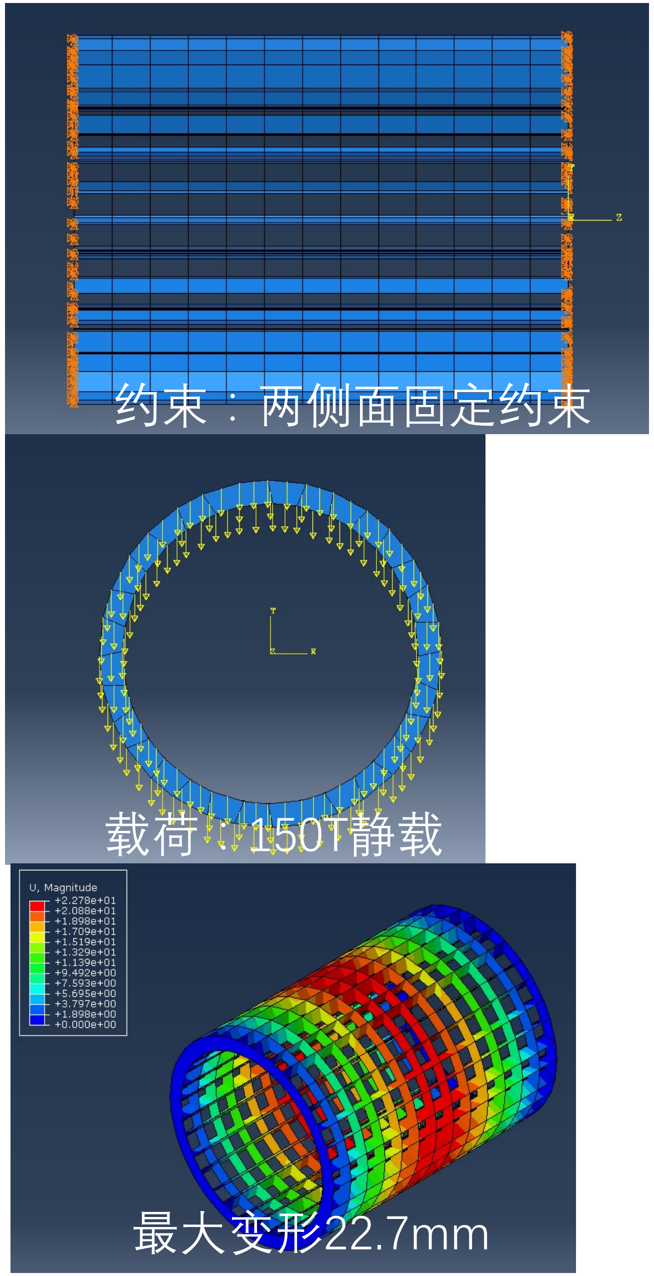
inlet

outlet



Next step, we will optimize the location of heating elements of PCB and add insulation between BGO and PCB.

与哈玻院有限元分析结果对比



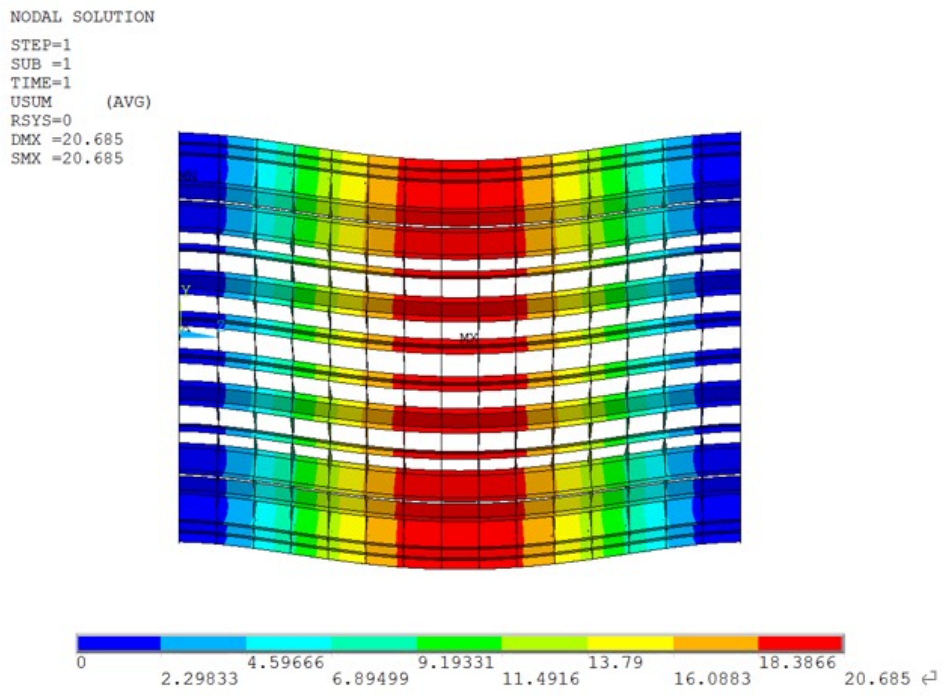
我的结果

4. **载荷及边界条件**

以自重方式将 135 吨负载附加在筒身上。并以过载形式加载于筒身。约束筒体两端。

5. **仿真结果**

T700 材料计算结果变形	20.68mm
M40 材料计算结果变形	13.65mm



T700 变形计算结果

哈玻院结果

	高能所	哈玻院
材料	T700	T700
荷载	150T	135T
变形	22.7mm	20.68

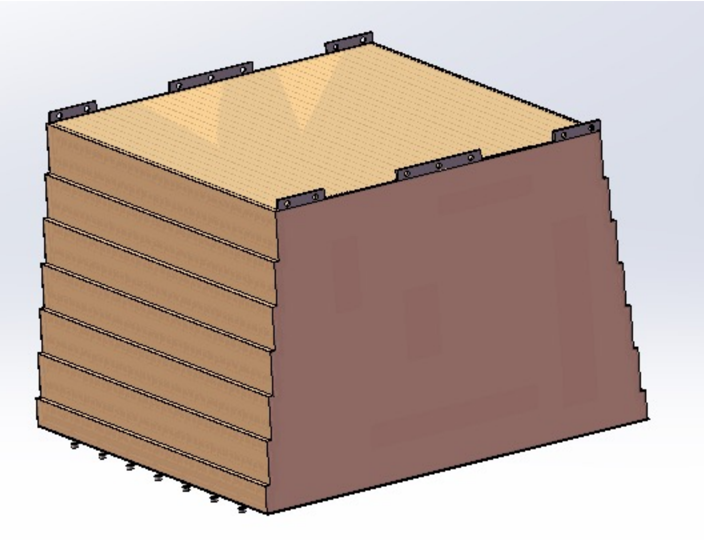
模拟方案为前期32边形正反梯形，两端支撑下变形计算。计算结果相吻合，证明计算方法和材料属性设置无误。

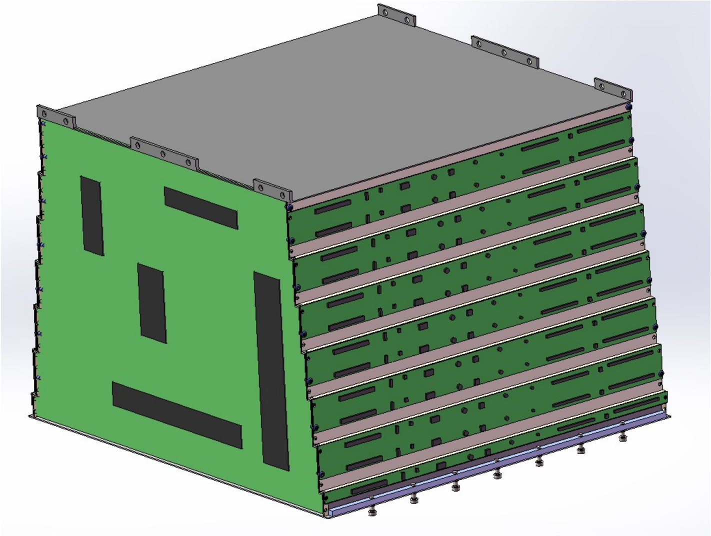
ECAL机械设计进展

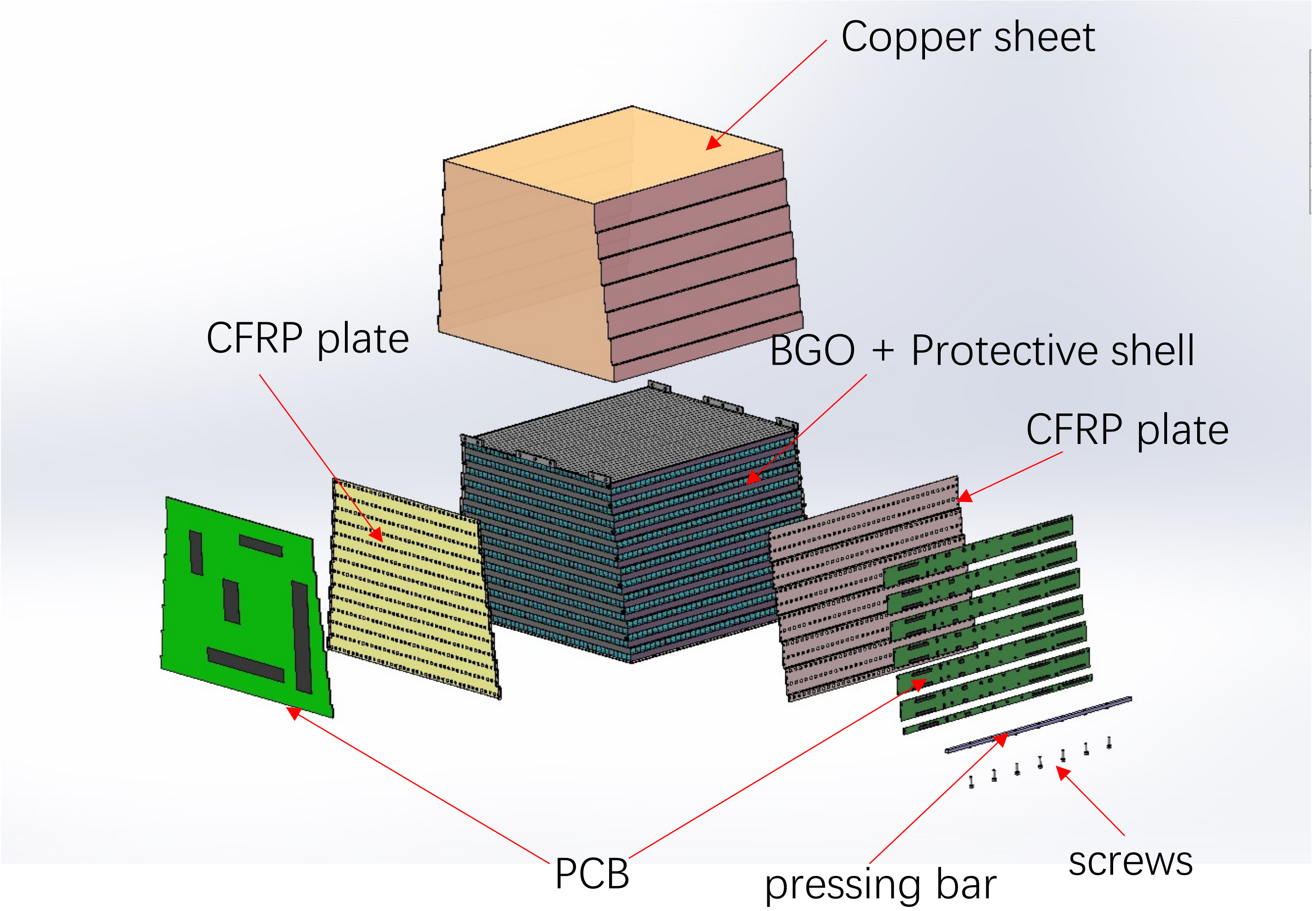
侯少静

10/11/2024

Structure of BGO module







ECAL机械设计进展

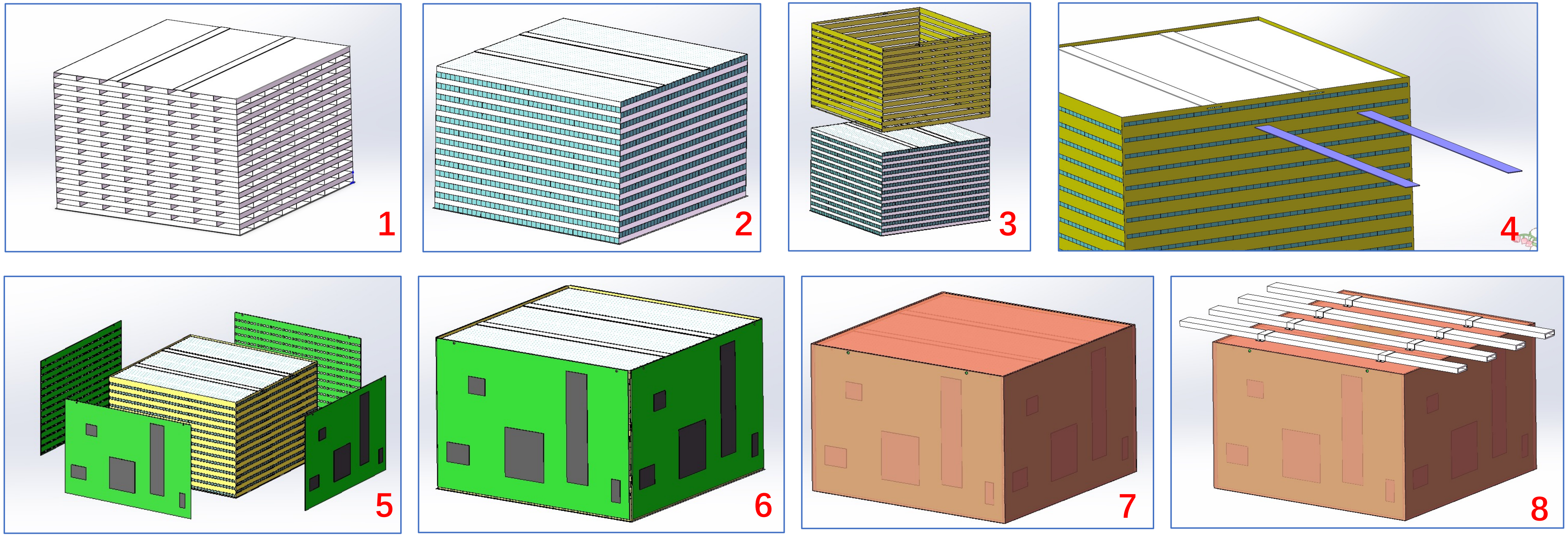
侯少静
09/24/2024

内容

1、ECAL筒部模块优化设计

2、厂家调研——结构工艺可行性验证

ECAL模块组装方案



组装步骤

1、定制碳纤维蜂窝保护壳；
2、将晶体插入保护壳，并在端部缝隙处填胶防止安装过程中滑动；
3、套碳纤维外壳，防止晶体滑出；
4、将碳纤维外壳与蜂窝保护壳用碳纤维插拔固定；

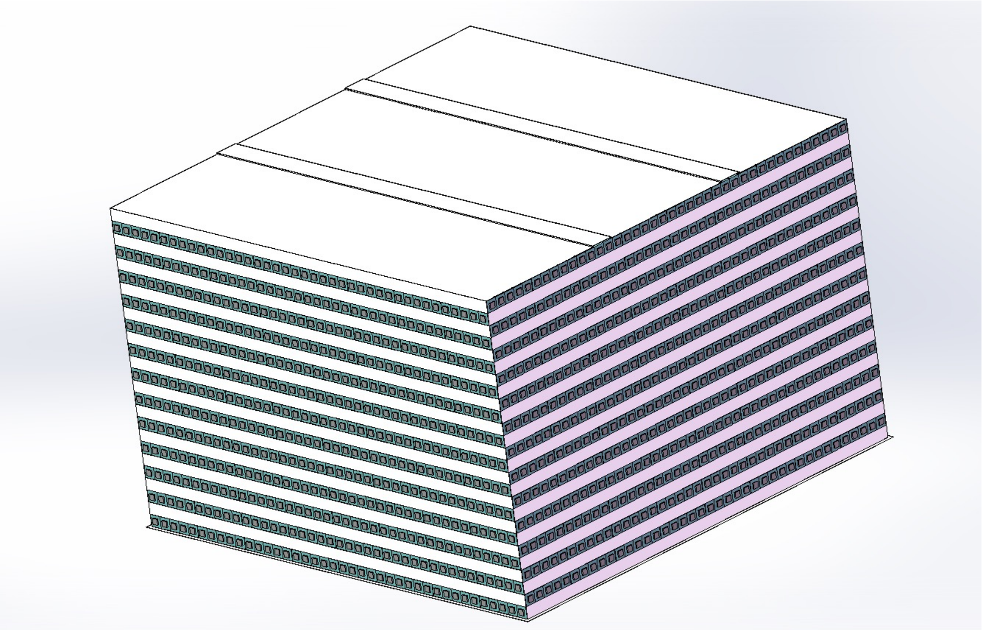
5-6、在碳纤维外壳四面安装电子学板；
7、在模块外壳安装铜壳帮助导热
8、在将模块安装到筒体上后，顶部安装散热铝管。

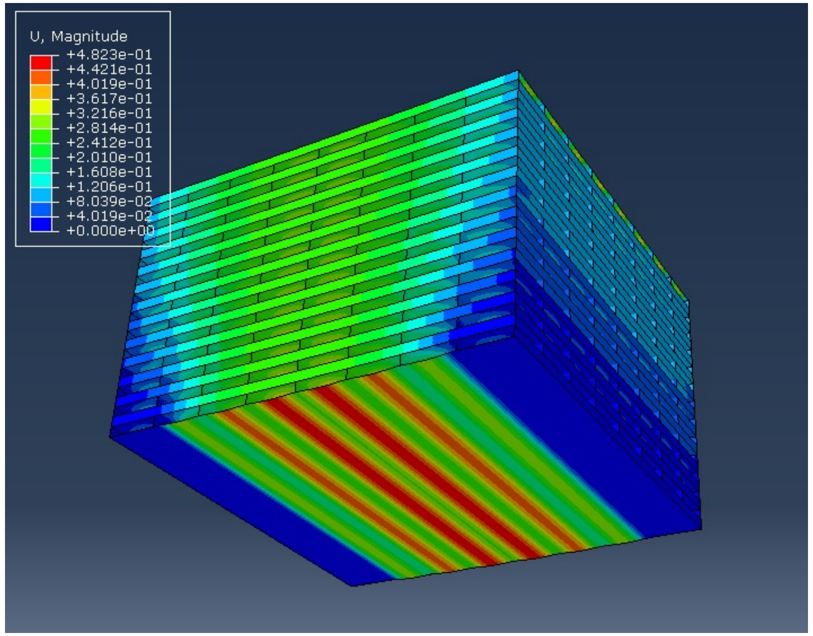
模块顶部侧壁与筒体采用螺栓固定。

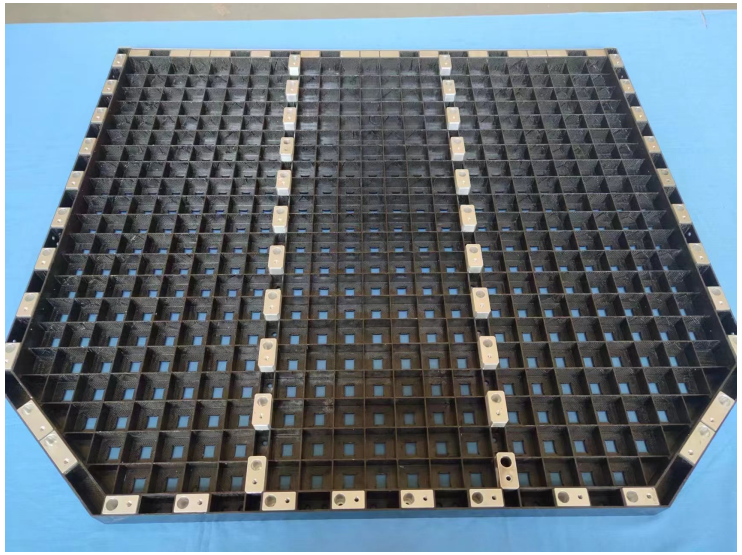
原模块设计方案

碳纤维保护壳有限元计算

碳纤维蜂窝保护壳





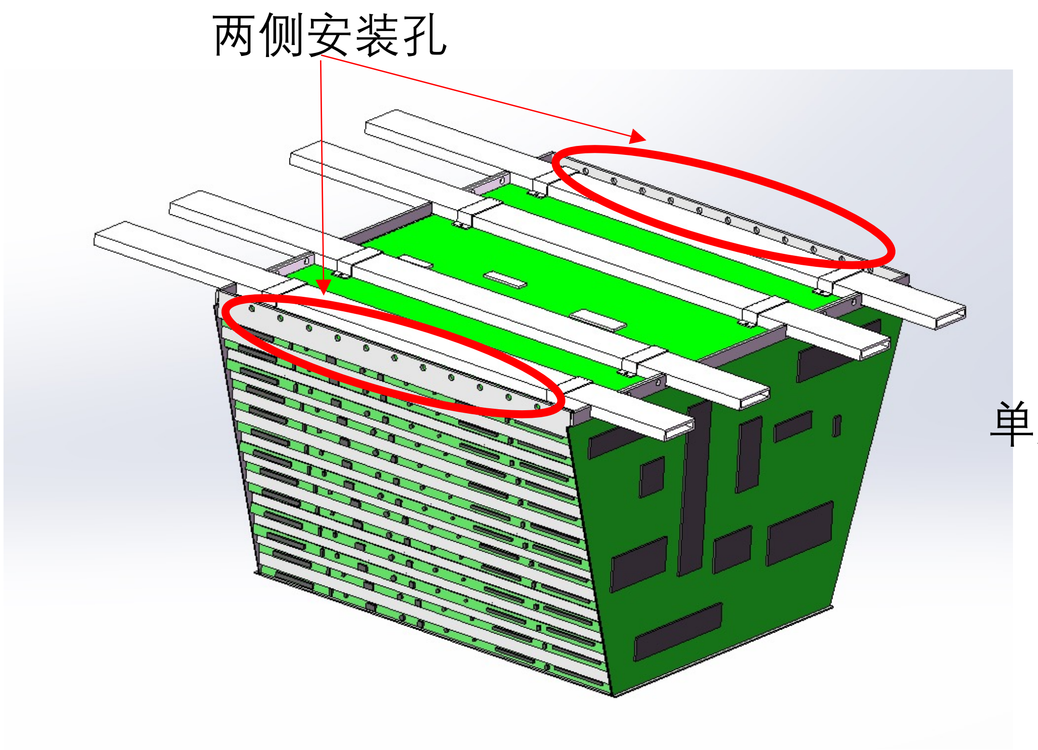


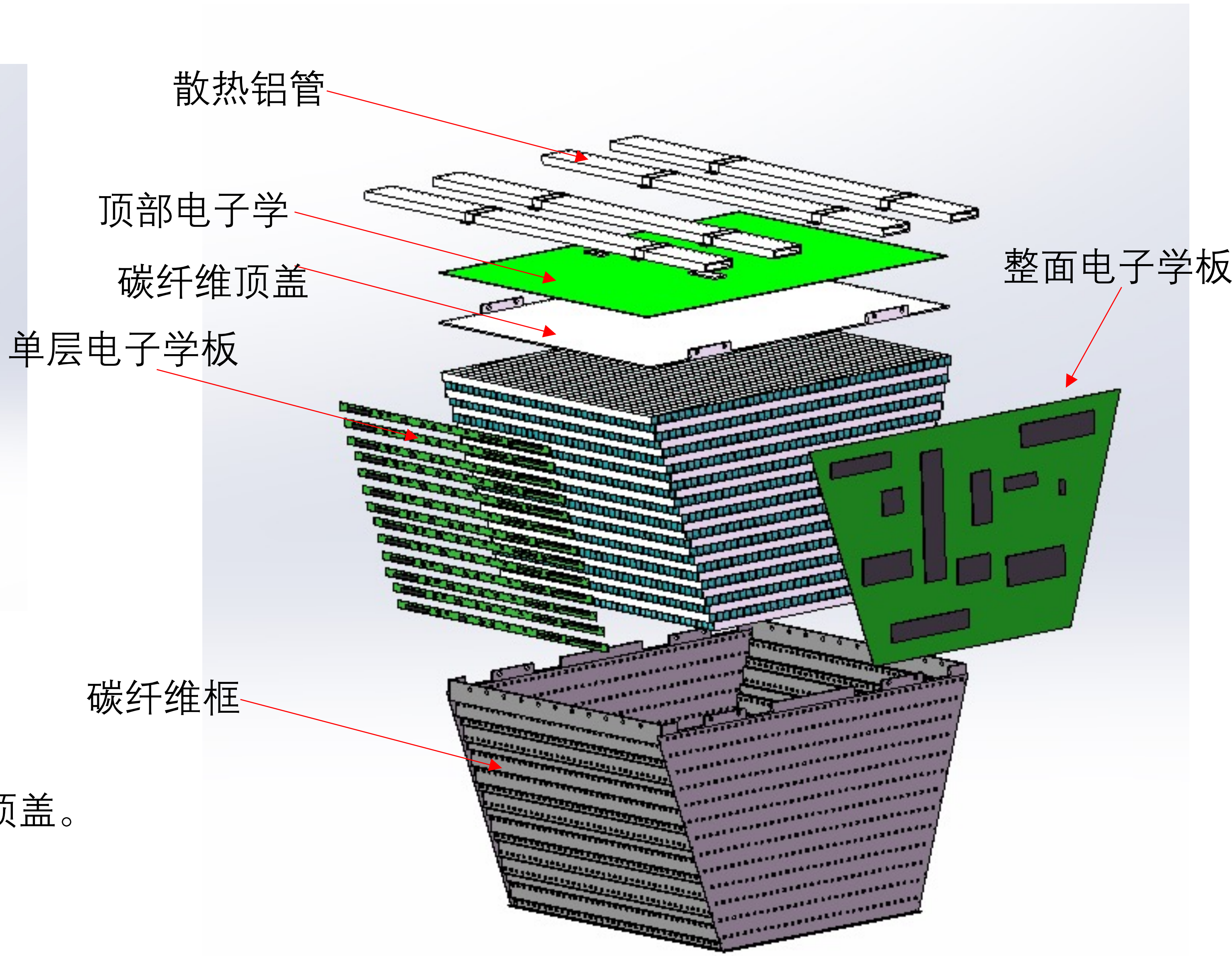
哈玻院类似产品：网格25*25mm，壁厚1.3mm，加工精度0.02mm

蜂窝层高：10mm
层板厚度：0.2mm
隔板厚度：0.4mm
总层数：26-28层

厂家反馈：
蜂窝结构层板厚度小，加工难度大，加工误差会比较大，达到0.1mm量级。

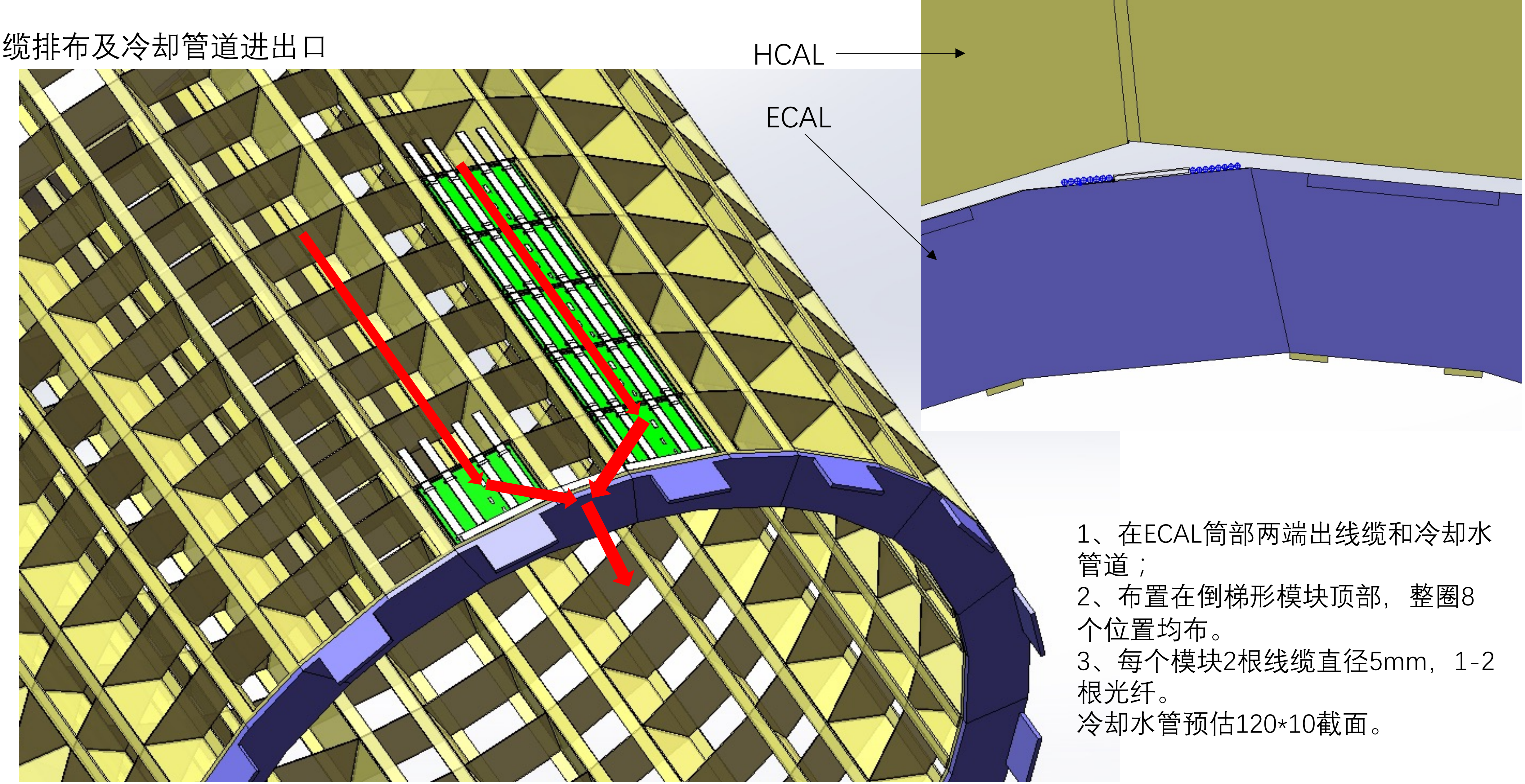
模块优化设计方案





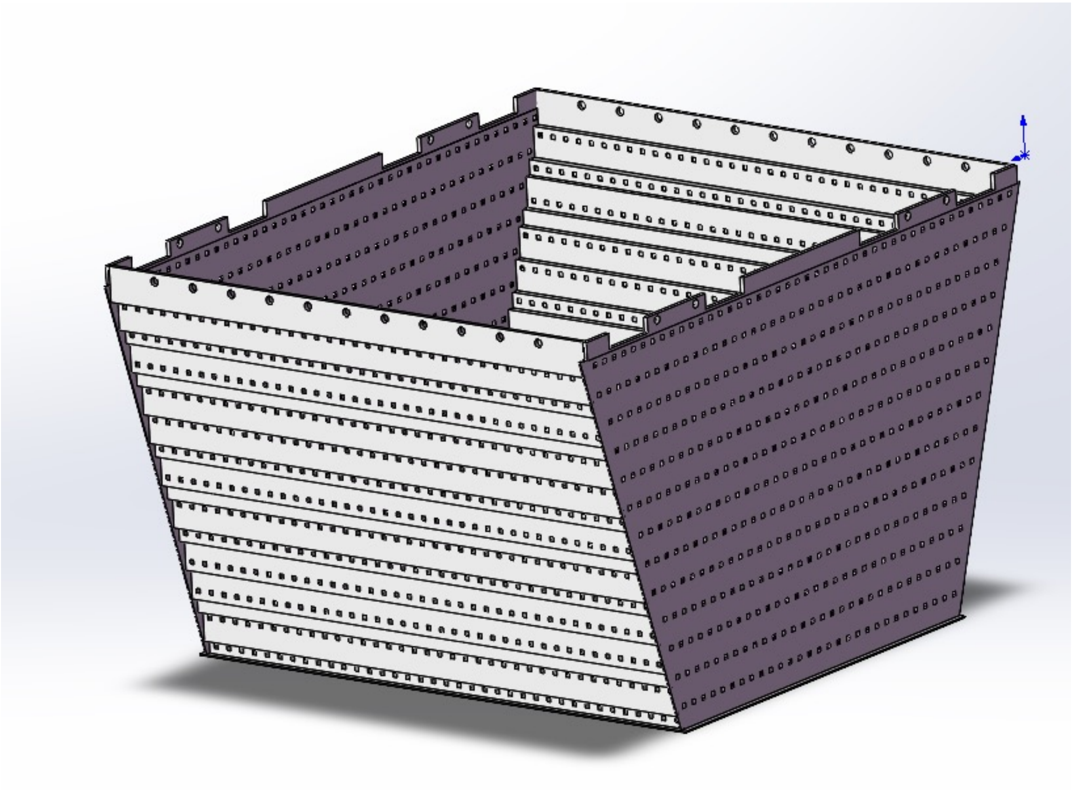
优化后的框架保留下底面和侧面，顶部加顶盖。

线缆排布及冷却管道进出口

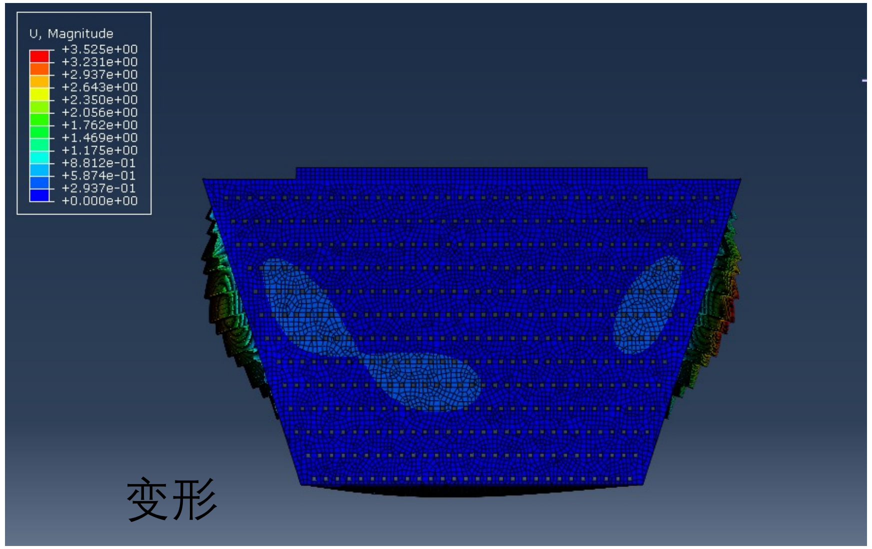


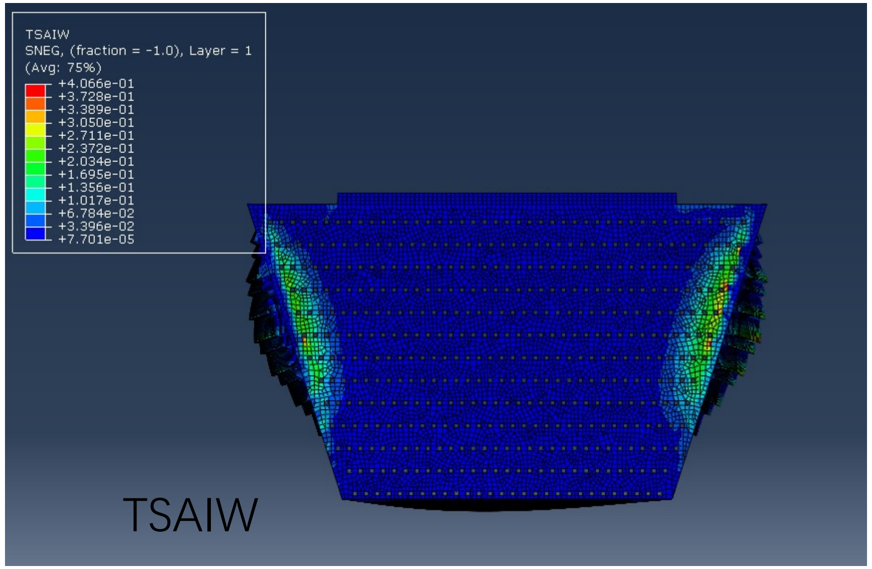
1、在ECAL筒部两端出线缆和冷却水管道；
2、布置在倒梯形模块顶部，整圈8个位置均布。
3、每个模块2根线缆直径5mm，1-2根光纤。
冷却水管预估120*10截面。

模块优化设计方案



下底面2mm、侧壁1mm、顶盖2mm





外壳应力及TSAIWU值均满足要求，变形量3.5mm，超出晶体可承受范围。下一步换高模量碳纤维进行计算。

厂家调研情况（哈尔滨玻璃钢研究院）

中国建材 China National Building Material Group Co.,Ltd.

相似产品

复合材料机架

产品特点：变截面型架，交叉一体成型。

主承力复合材料舱段结构示意图

主承力复材舱段主要由后舱、发动机及气瓶安装结构、底端支撑接口结构、起吊支撑结构组成。其中后舱为复杂截面型材框架、蒙皮结构异性结构，

与ECAL主结构工艺相同，左图直径2米多。

厂家调研情况

复合材料整流罩

整流罩是我院首件为商业航天研制的民用火箭整流罩，整个产品的构型结构均为我院设计。

相似产品

工艺：ECAL主结构，网格结构工艺实现没问题，网格精度可控制在0.1mm量级。

价格：T700碳纤维 3000/kg，M40碳纤维 30000/kg（不精确估计），不含模具费用。

主结构1.5T

谢谢！