Status of the calorimeter WP

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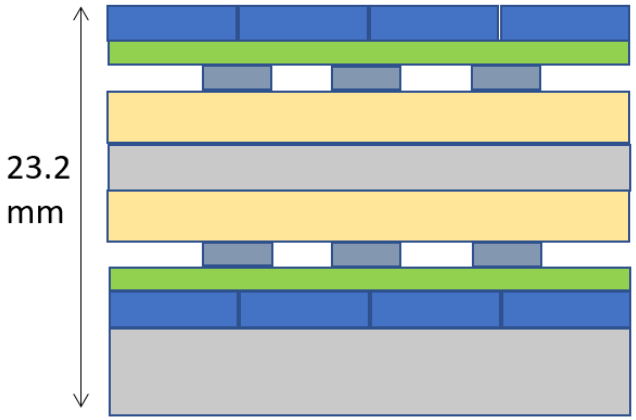
for the CEPC calorimeters working group
April 23, 2024

Updated calorimeters dimensions

CEPC塑闪ECAL

ECAL 超层（一个超层包含二层）



闪烁体+反射层，2.2 mm

PCB+元器件，3.2 mm （1.2 mm + 2.0 mm）

散热Cu板，3 mm (0.2 X_0，0.020 NIL)

吸收体（W:Cu，75:25），2.1 mm (0.4 X_0，0.018 NIL)

散热Cu板，3 mm (0.2 X_0，0.020 NIL)

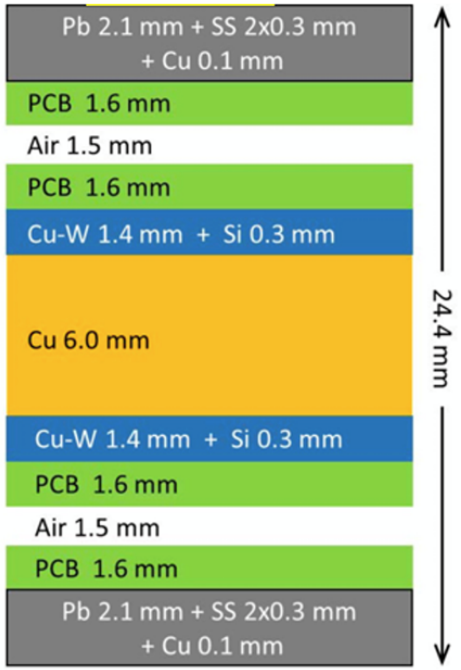
PCB+元器件，3.2 mm （1.2 mm + 2.0 mm）

闪烁体+反射层，2.2 mm

吸收体（W:Cu，75:25），4.3 mm (0.8 X_0，0.036 NIL)

单个超层：1.6 X_0，0.09 NIL
15个超层，24 X_0，1.35 NIL，348 mm

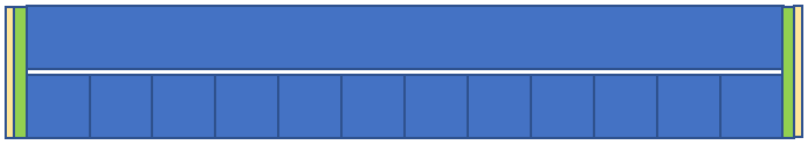
CMS硅ECAL



14个超层，25 X_0，341.6 mm

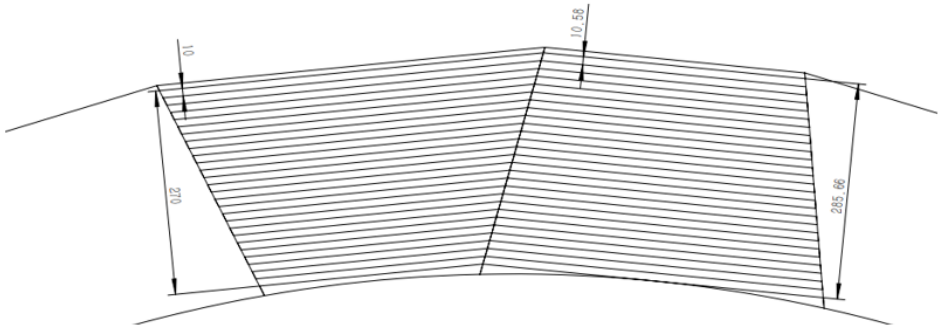
CEPC正交长条晶体ECAL： 总厚度 ~ 290 mm

晶体ECAL： 相邻两层为正交排布的晶体条

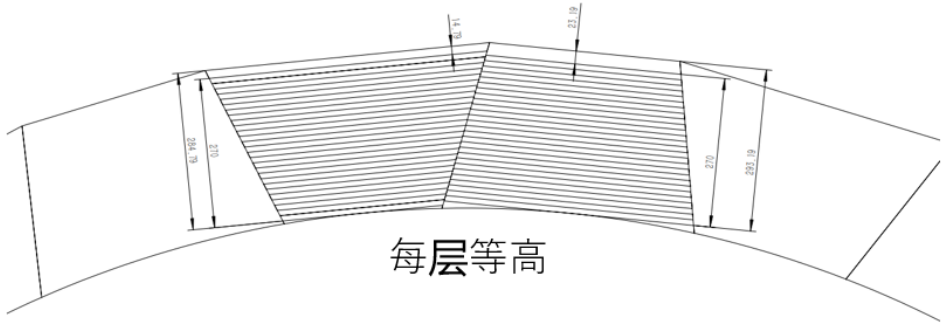


- 单根BGO闪烁晶体厚度: 10 mm
- 共27层晶体，晶体总厚度为270mm，对应24.1 X_0，1.21 NIL
- 如果每根晶体每个面的包装层厚度为0.1mm，则包装层总厚度约5mm，此时晶体总厚度为275mm
- 模块顶部的数据汇总和传输，以及冷却系统占用厚度预期不超过10mm，则量能器总厚度约285mm
- 碳纤维支撑结构在厚度上的额外贡献 ~ 5 mm

晶体长度约为400mm，实际长度跟所在层数相关
（以上仅为示意图，不按比例）
晶体模块侧面包括电子学读出板和被动冷却层（铜）

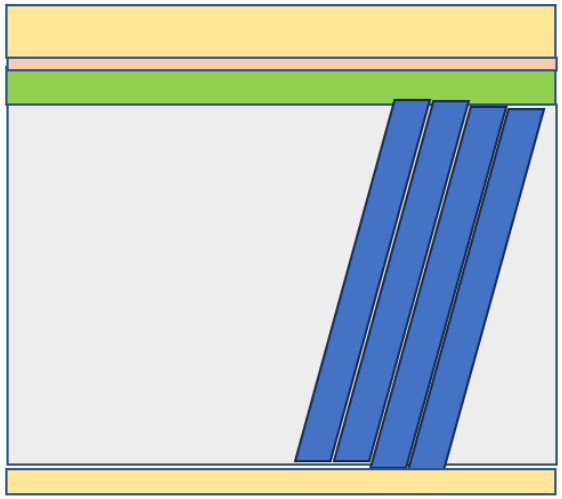


每**层对应**，但每层不等高



每**层**等高

CEPC 倾斜长条晶体ECAL：圆柱形轮廓，总厚度~297 mm

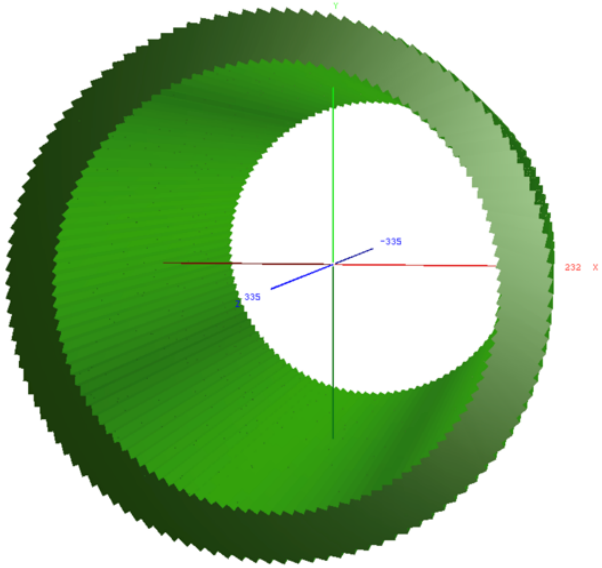


碳纤维支撑圆桶10mm
散热铜片3mm
PCB+光电器件+电子学 + 传输线缆+供电电缆：10mm

BGO晶体269mm （24X0，1.21NIL）

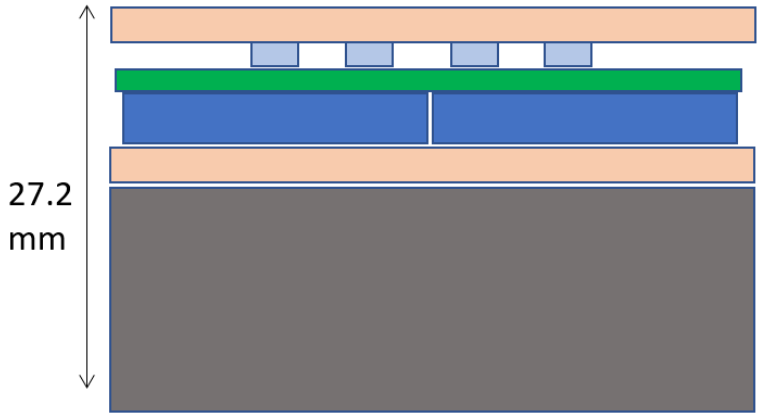
ESR 外包装厚度 ~80 um/面，ESR总厚度= 80 um/sin(20度)*2面*10层 = 4.7mm

共计274mm



保守设计可以在内部增加3mm碳纤维支撑层

CEPC PS-AHCAL



上盖板 2 mm

PCB+元器件，3.2 mm

闪烁体+反射层，3.2 mm

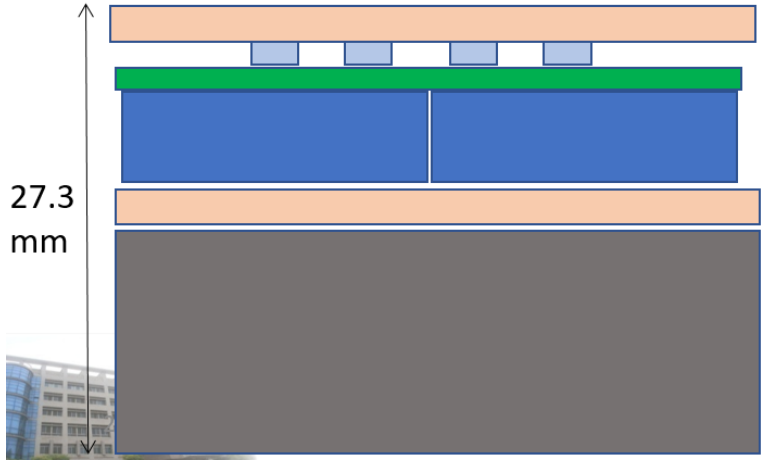
下盖板 2 mm

吸收体，16.8 mm

单层（未考虑闪烁体和PCB）：1.18 X_0，0.125 NIL
48层：56.8 X_0，6.0 NIL，1305.6 mm

注：塑闪的总厚为14.4cm，约0.19 NIL，对应31.6mm的铁。如果考虑这部分贡献，在相同总NIL下，PS-AHCAL相比GS-AHCAL可以更薄，即1305.6-31.6=1274 mm

CEPC GS-AHCAL



上盖板 2 mm

PCB+元器件，3.2 mm

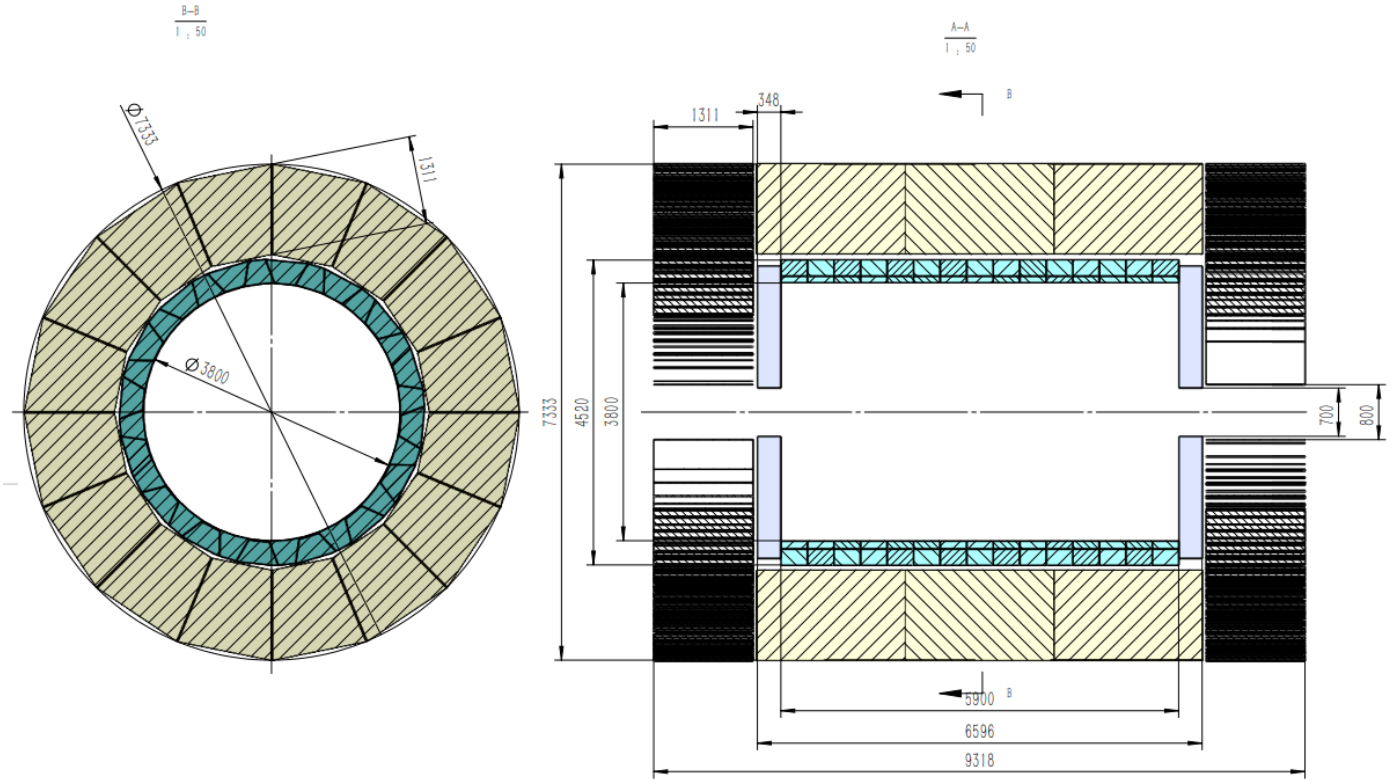
闪烁玻璃+反射层，10.2 mm

下盖板 2 mm

吸收体，9.9 mm

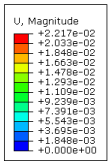
单层：(未考虑PCB） 1.41 X_0，0.125 NIL
48层：67.7X_0，6.0 NIL，1310.4 mm

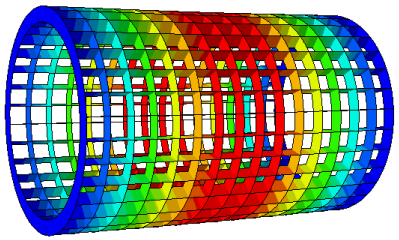
Updated calorimetry layout

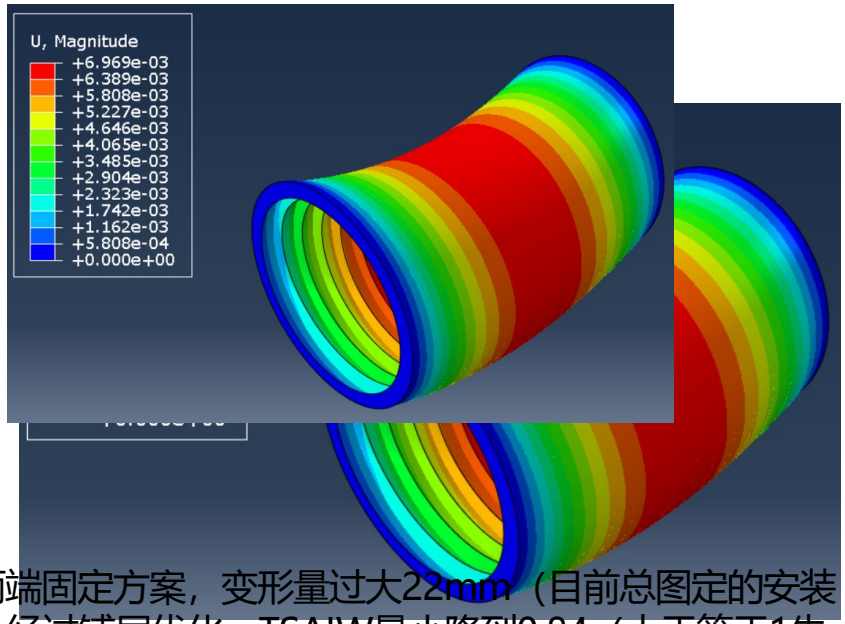


Gap between ECAL and HCAL: 50 mm
Gap between barrel and endcaps: ?

Mechanical structure design and simulation for crystal ECALs







主要结论：

1、栅格方案：1cm厚碳纤维复合材料，如果按照目前的两端固定方案，变形量过大22mm（目前总图定的安装间隙为15mm）； 增加筒体中部支撑后，变形降到4mm; 经过铺层优化，TSAIW最小降到0.84（大于等于1失效)

2、Stereo 方案：简化计算模型，简化后的模型不体现挖孔，偏安全; 1cm厚碳纤维复合材料，最大变形量约7mm；TSAIW值0.3，满足要求。 后续调整计算模型。

Price tags

		单位	单价 （人民币）	备注	参考
灵敏物质	塑料闪烁体+包装	channel	3.5	ScECAL	CEPC R&D 样机
		channel	7.5	AHCAL	CEPC R&D 样机
	硅	cm^2	28		CMS HGCAL, 1 CHF ~ 8 CNY
	BGO晶体	cm^3	65		询价SIC，含税13%
	玻璃	cm^3	18	GSHCAL	1/3 of BGO
吸收体	钨	kg	885	ScECAL & SiW ECAL	ILD, 1 USD ~ 7.2 CNY
	无磁不锈钢	ton	56000		CALICE SDHCAL
电子学	SiPM	片	10	1.3*1.3 mm	根据3*3 scale得到
			56	3*3 mm	HGCAL,
			200	6*6 mm	根据3*3 scale得到
	前端电子学总价	channel	20	SiPM电子学，塑闪4*4 cm^2	HGCAL
		channel	3.6	数字读出电子学，1*1 cm^2	CALICE SDHCAL样机。

First exercise of cost estimation (preliminary, in RMB)

- Si-ECAL: 1484 M
- Sci-ECAL: 994 M
- Crossing crystal ECAL: 1898 M (cost of carbon fiber supporting structure is missing)
- Stereo crystal ECAL: 1876 M (cost of carbon fiber supporting structure is missing)
- RPC-SDHCAL: 487 M
- PS-AHCAL: 293 M
- GS-AHCAL: ~ 2-3 B (two cost drivers: GS and SiPM, to be optimized)

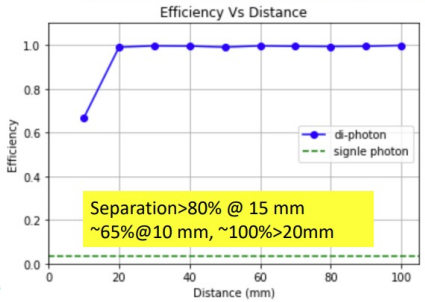
Thanks

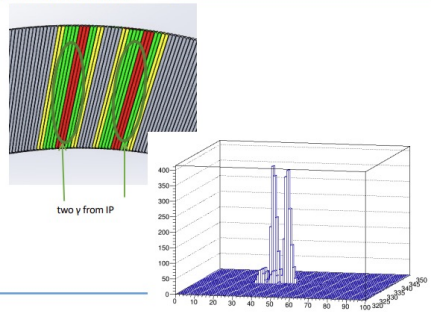
Stereo crystal ECAL progress

Separation between two 5 GeV photons

- Two 5 GeV photons, vary distance along phi between them
- Success reconstruction: 2 neutral particles, 3.3GeV<Eγ<6.6GeV for each photon
- **Separation and energy regression using end-to-end NN**
  - trained with flat distributed photon energy and distances

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.108.052002

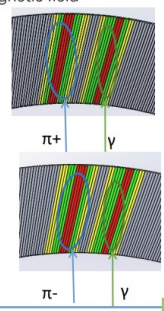


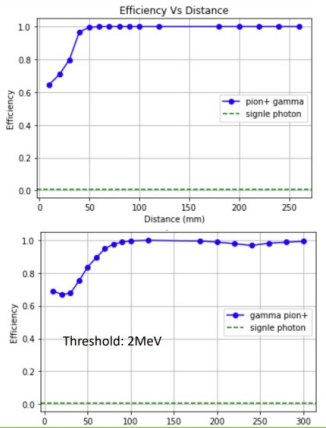


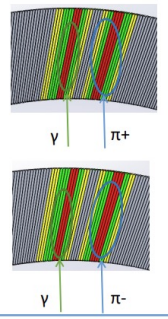
Separation between γ/π

- 5 GeV γ/10GeV π, vary distance along phi between them
- Separation use end-to-end NN
- Success reconstruction: 3.3GeV<Eγ<6.6GeV not yet applied
- Different π/γ separation power: pointing angle / magnetic field

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.108.052002



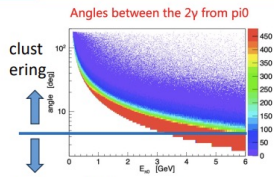




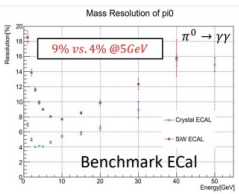
Trained with a sample of 1-10GeV γ, 2-20GeV pi+, distance @calor variated around 20 mm

Pi0→2phton invariant mass

- End-to-end NN regression is used
  - Trained with di-photon events with flat distributed momentum from x GeV to XX GeV, distant < 3 degree
  - Apply to samples of pi0→di-photon with different pi0 moment



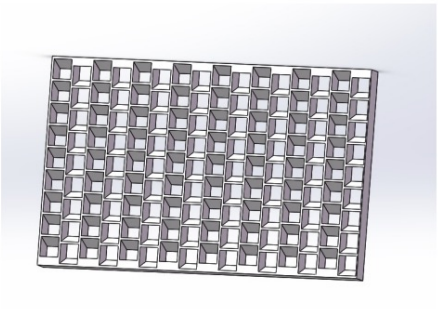
End-to-end NN regression

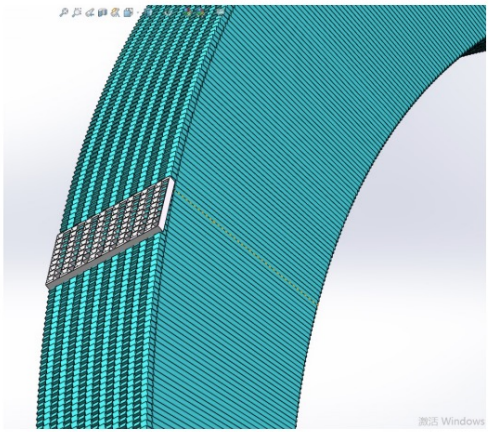


Benchmark ECal

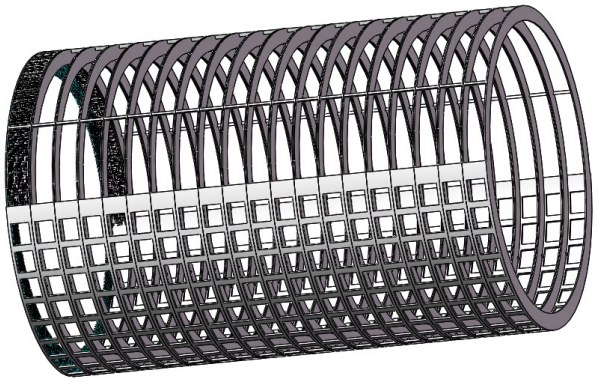
Stereo crystal ECAL mechanical design

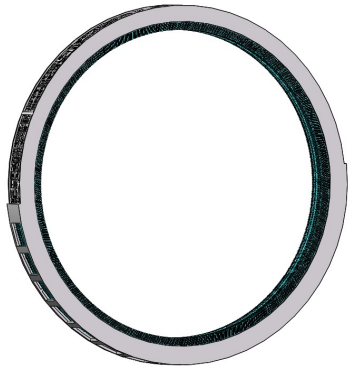
Aggressive version

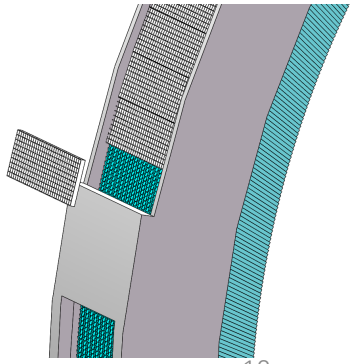




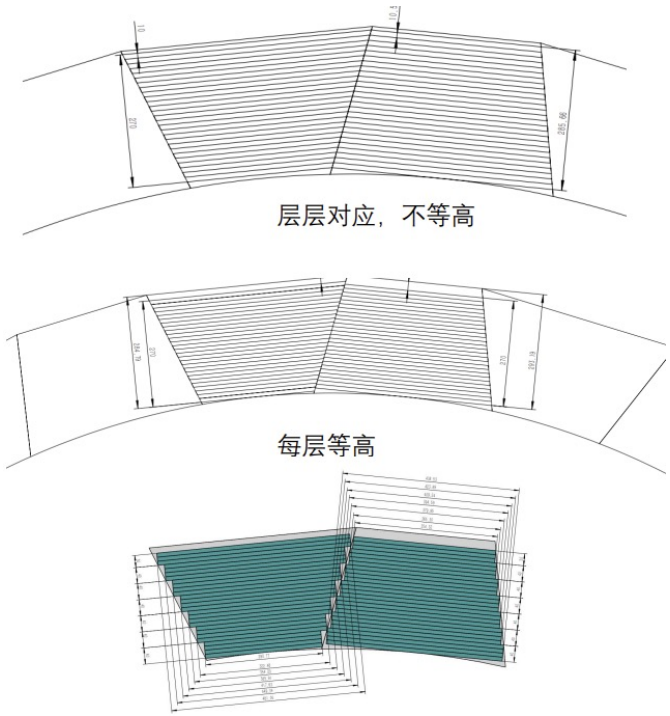
Conservative version

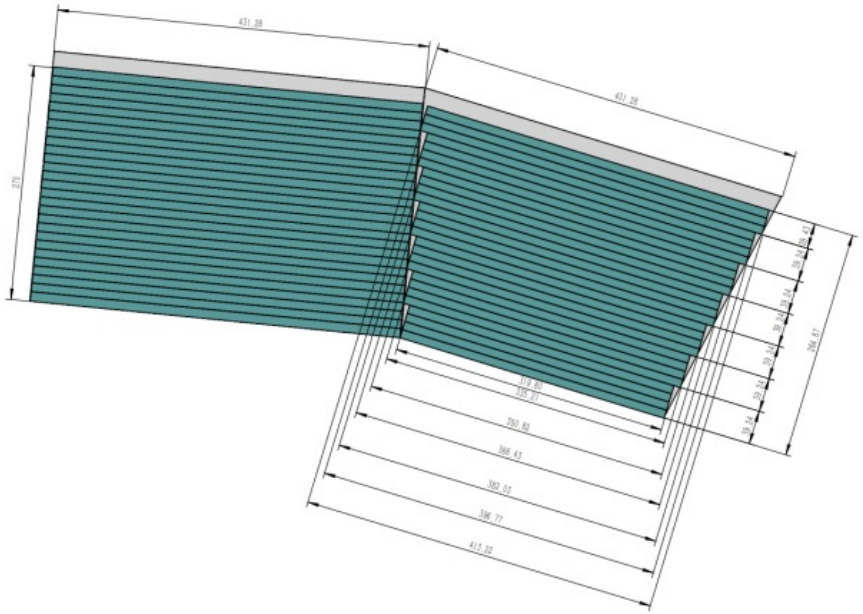






Crossing-bar ECAL module design





Photon detectors for crystal ECALs

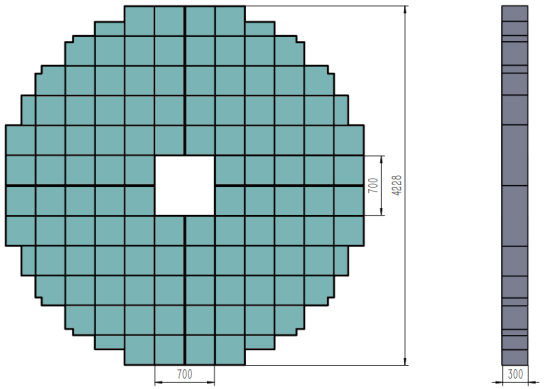
SiPM vs APD vs PD

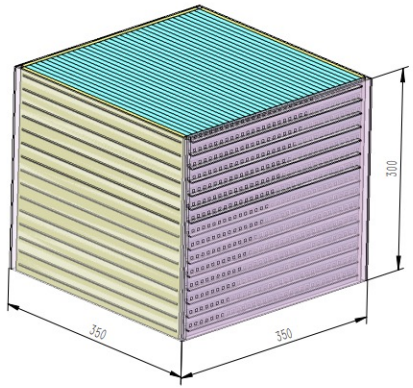
	SiPM （S14160-3010PS）	APD （S8664-55）	PD （S1227-33BR）
价格	中（较高）	中（有不确定性）	低
单光子测量	是	否	否
时间测量	~10ps (lab)	~1ns (CMS)	?
线性范围	差	好	好
抗辐照	中	强	中
是否满足Stereo Ecal要求	是	是	是
刻度…	单光子	激光	氙气灯
已有实验		CMS	L3(its PD is not available now)

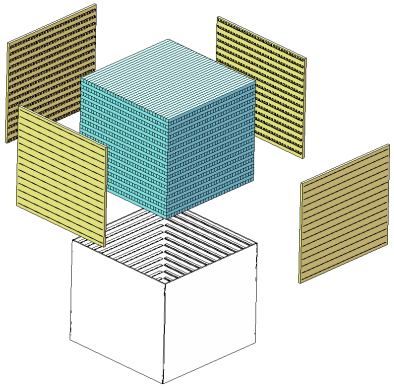
BGO： 8-10 photon/keV
Lower threshold： 2MeV: → 20,000 photons * efficiency

Endcap layout

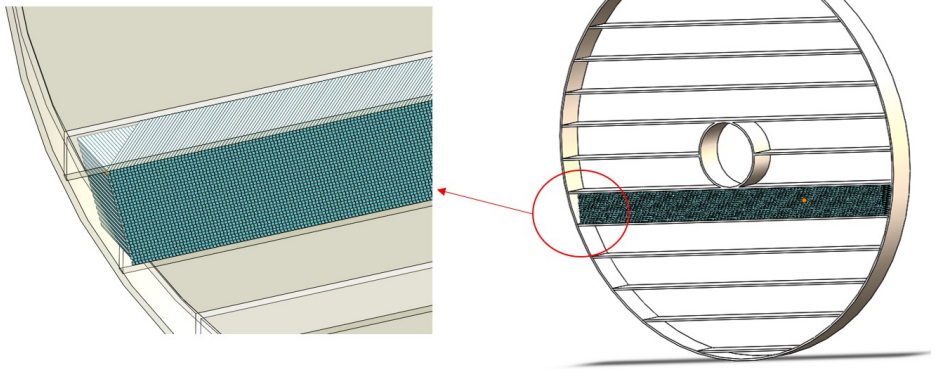
Crossing-bar crystal ECAL endcap



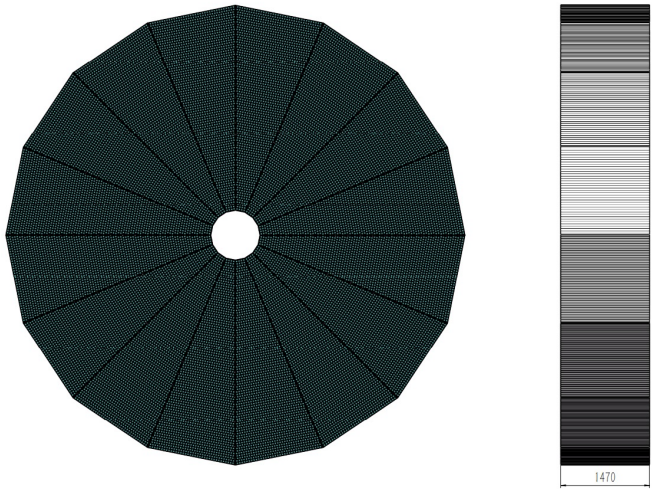




Stereo crystal ECAL endcap

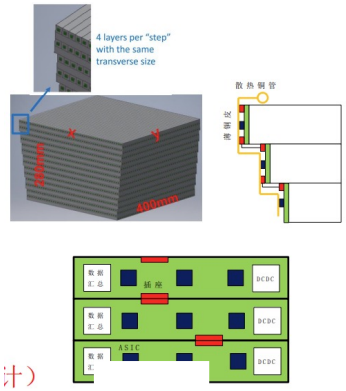


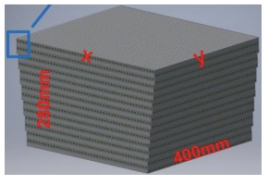
HCAL endcap

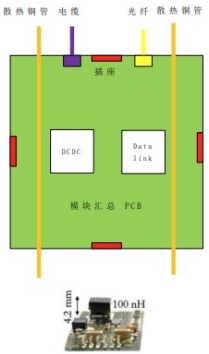


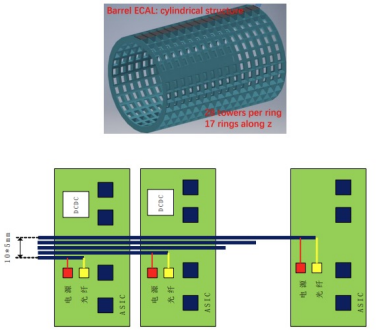
Readout electronics

Crossing-bar crystal ECAL readout scheme

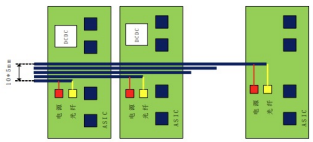


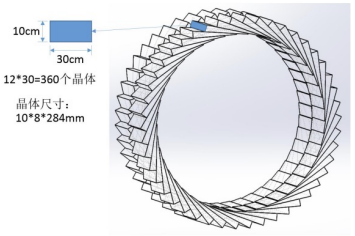




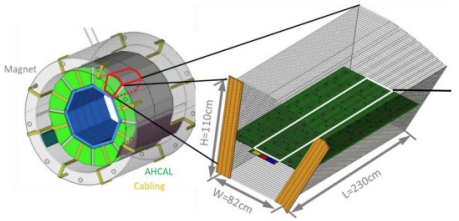


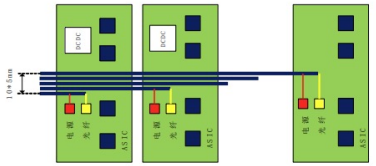
Stereo crystal ECAL电子学方案



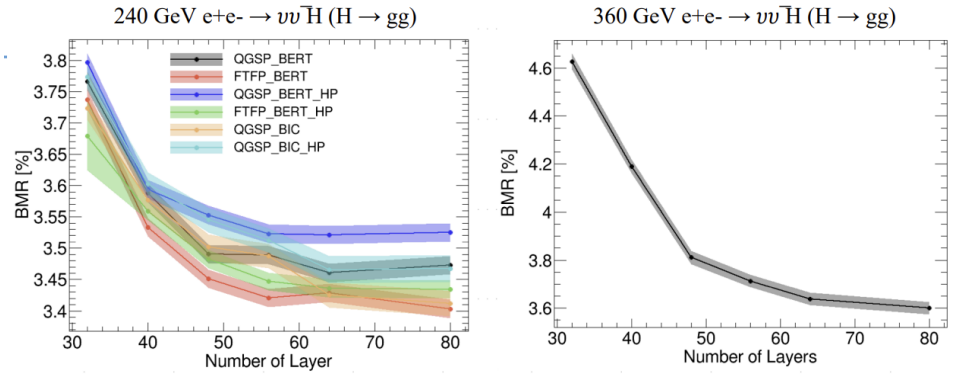


HCAL readout scheme





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



GSHCAL2 extrapolated to 48 layers (~6 lambda) including front-end readout PCBs (from CEPC AHCAL R&D)