Plastic scintillator ECAL and HCAL

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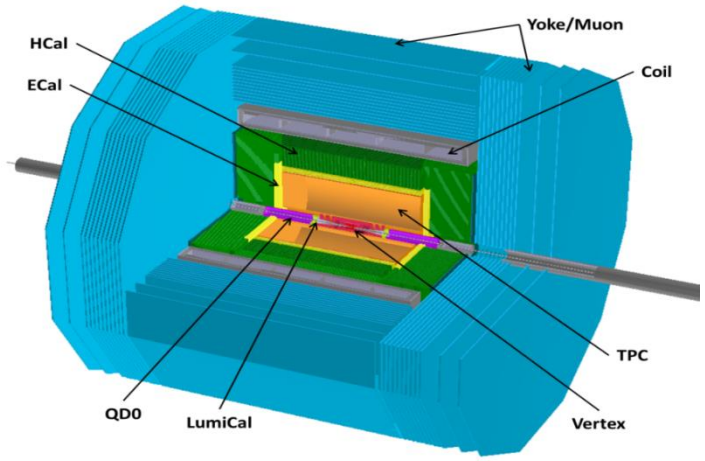
Requirements of CEPC Calorimeter

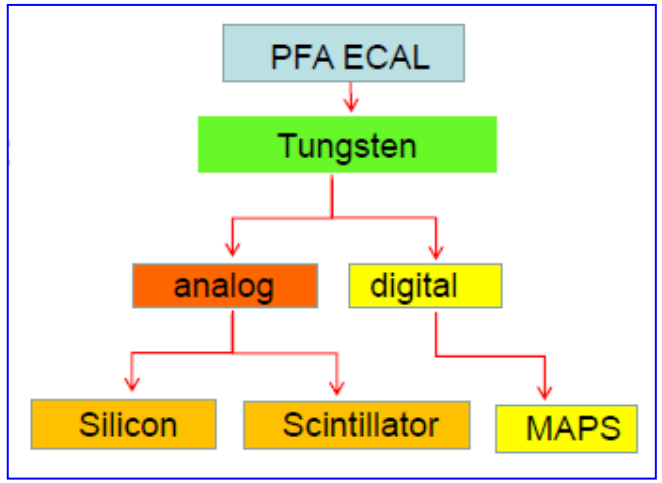


- **ILD-like detector with additional considerations.**

Challenges:

- **Momentum:** $\sigma_{1/p} < 5\times10^{-5}\ \mathrm{GeV}^{-1}$
- **Impact parameter:** $\sigma_{r\phi} = 5 \oplus 10/(p\cdot\sin^{\frac{3}{2}}\theta)\ \mu\mathrm{m}$
- **Jet energy:** $\frac{\sigma_E}{E} \approx 3-4\%$

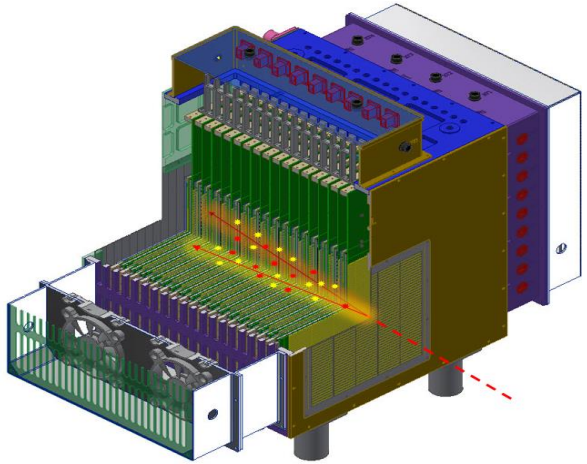
- The Particle Flow Algorithm (PFA) calorimeter concept was proposed
  - High granularity
  - Good track finding
  - Good energy resolution



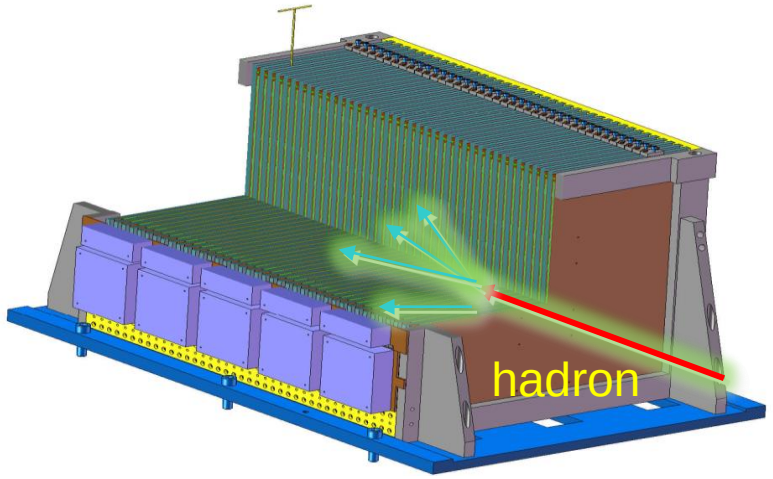
PFA Calorimeter

Sampling Calorimeter

Calo	Sampling No.	Sensitive detector	Absorber	Granularity	Electronics	Absorb length	Energy Resolution	weight
Sci-W ECAL	32	PSD+SiPM	W-Cu	5mm×5mm	SP-2E	22 X_0	16%@ 1 GeV	0.3 T
AHCAL	40	PSD+SiPM	Fe	40mm×40mm	SP-2E	4.6 NIL	60%@ 1 GeV	5.0 T



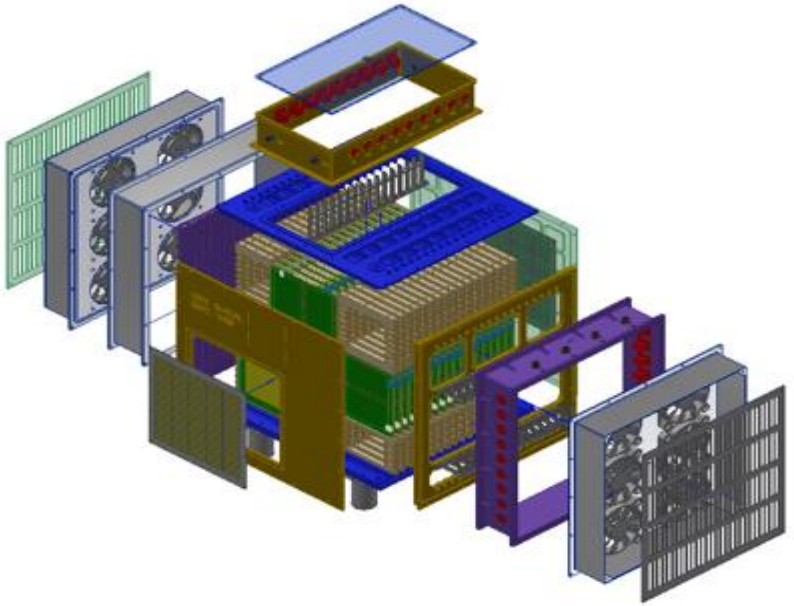
Sci-W ECAL

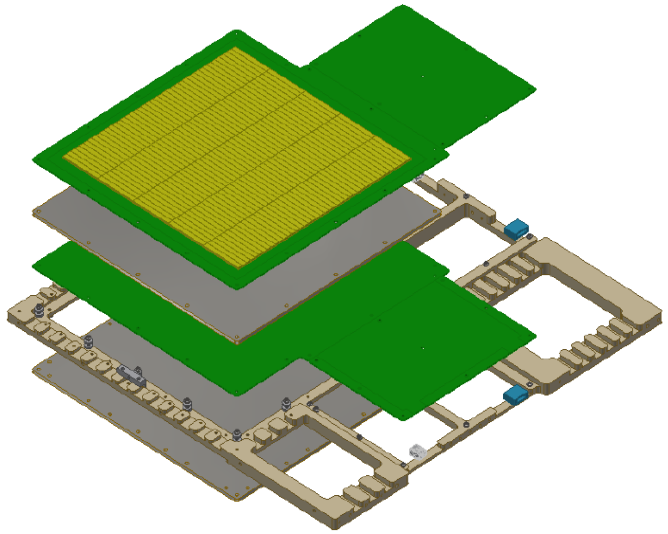


AHCAL

Sci-W ECAL

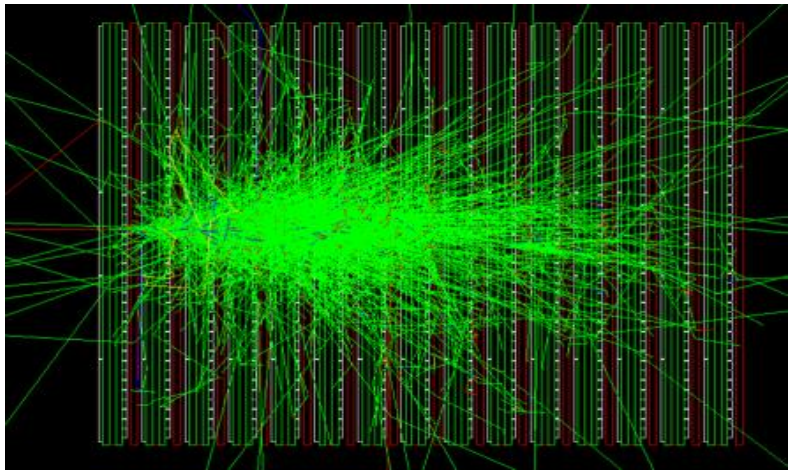
- Sci-W ECAL
  - 32 layers，16 super-layes
  - 210 channels of each layer，
    total channels:6720
  - Sensitive area：22cm×22cm

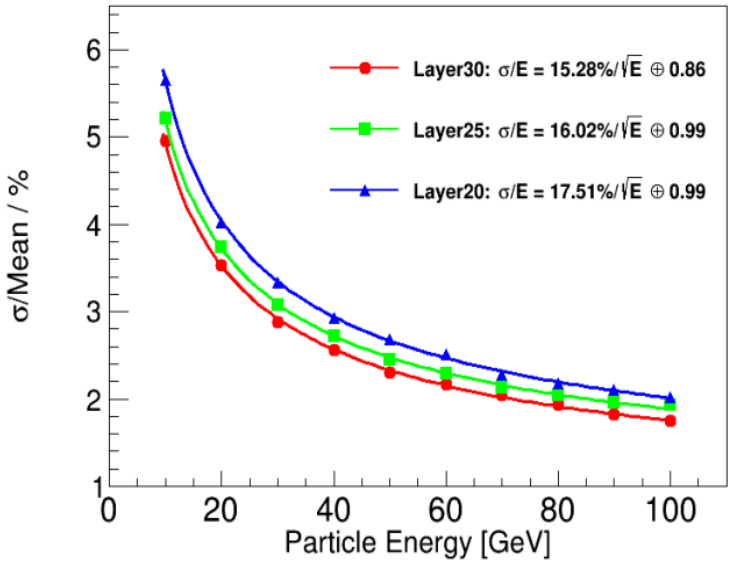


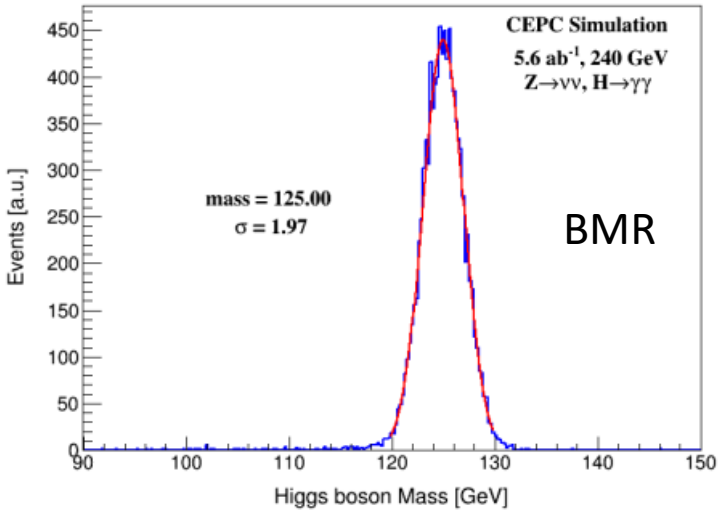


ECAL

- ◆能量分辨率16%@1GeV
- ◆BMR：1.97% （H->γγ）

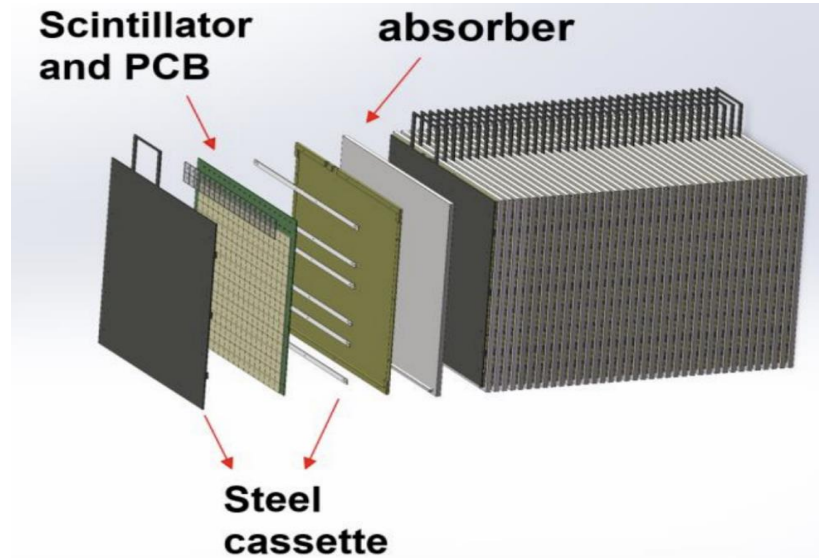


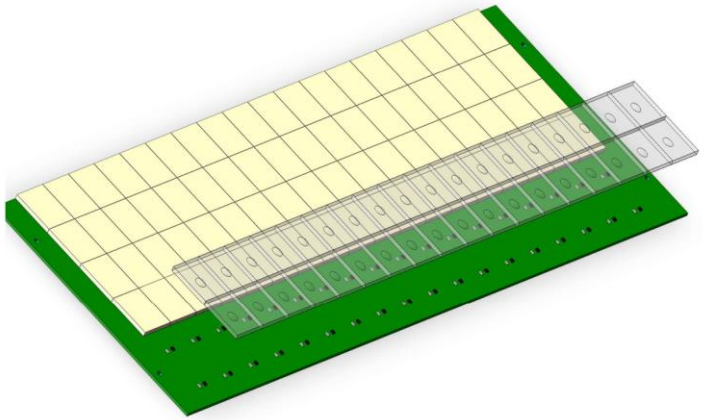


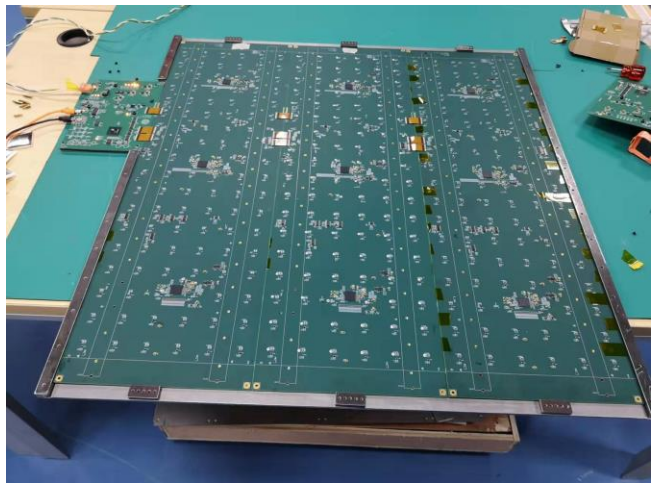


AHCAL

- The AHCAL was assembled this summer
  - 40 sensitive layers, and sensitive area is
    ~ 72 cm x 72 cm
    - Each layer has 324 sensitive cells
    - Total number is 12960

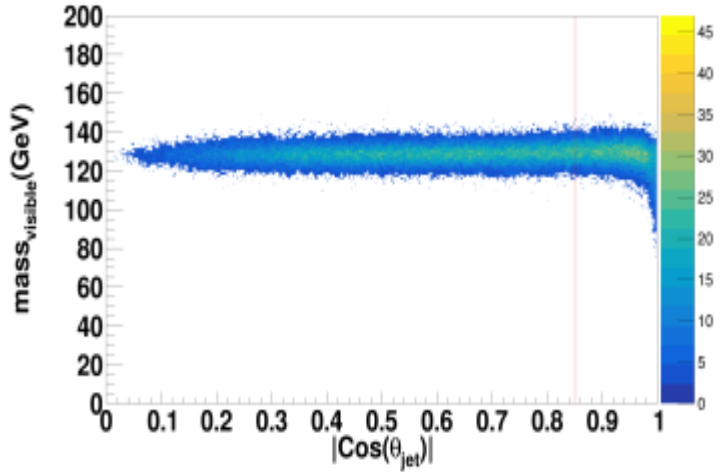


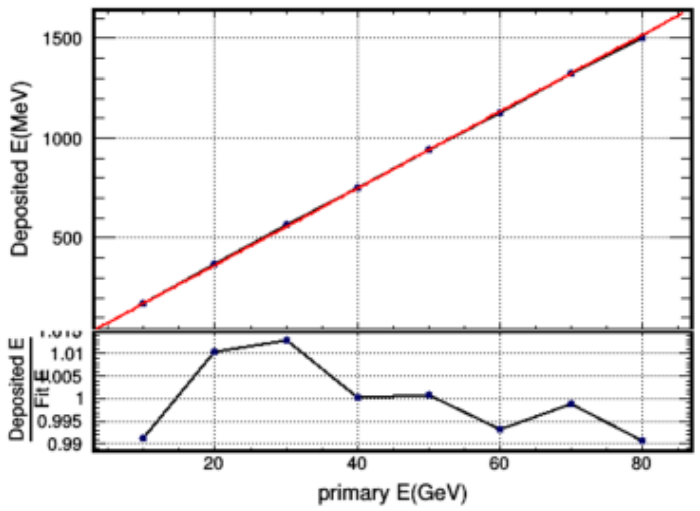


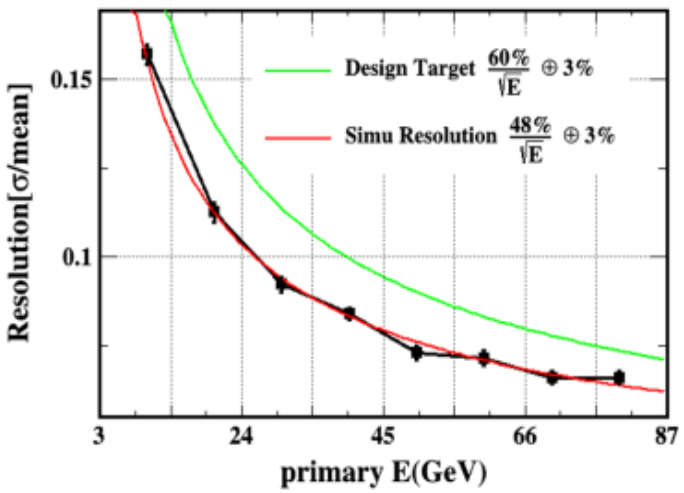


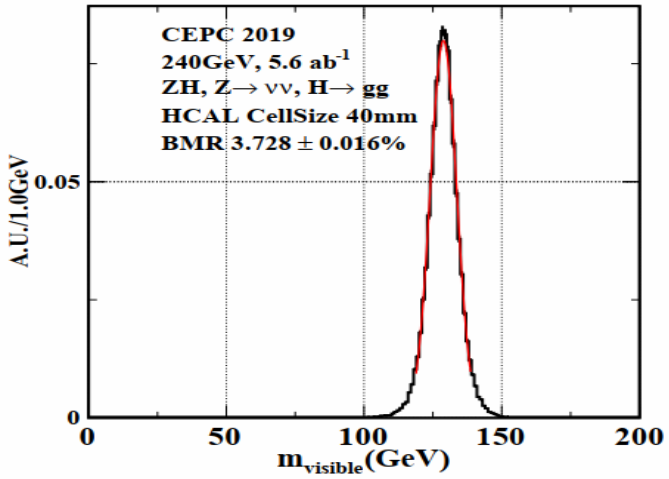
AHCAL

- ◆能量线性优于1%
- ◆能量分辨率~48%@1 GeV
- ◆BMR ~3.7% （H->gg）

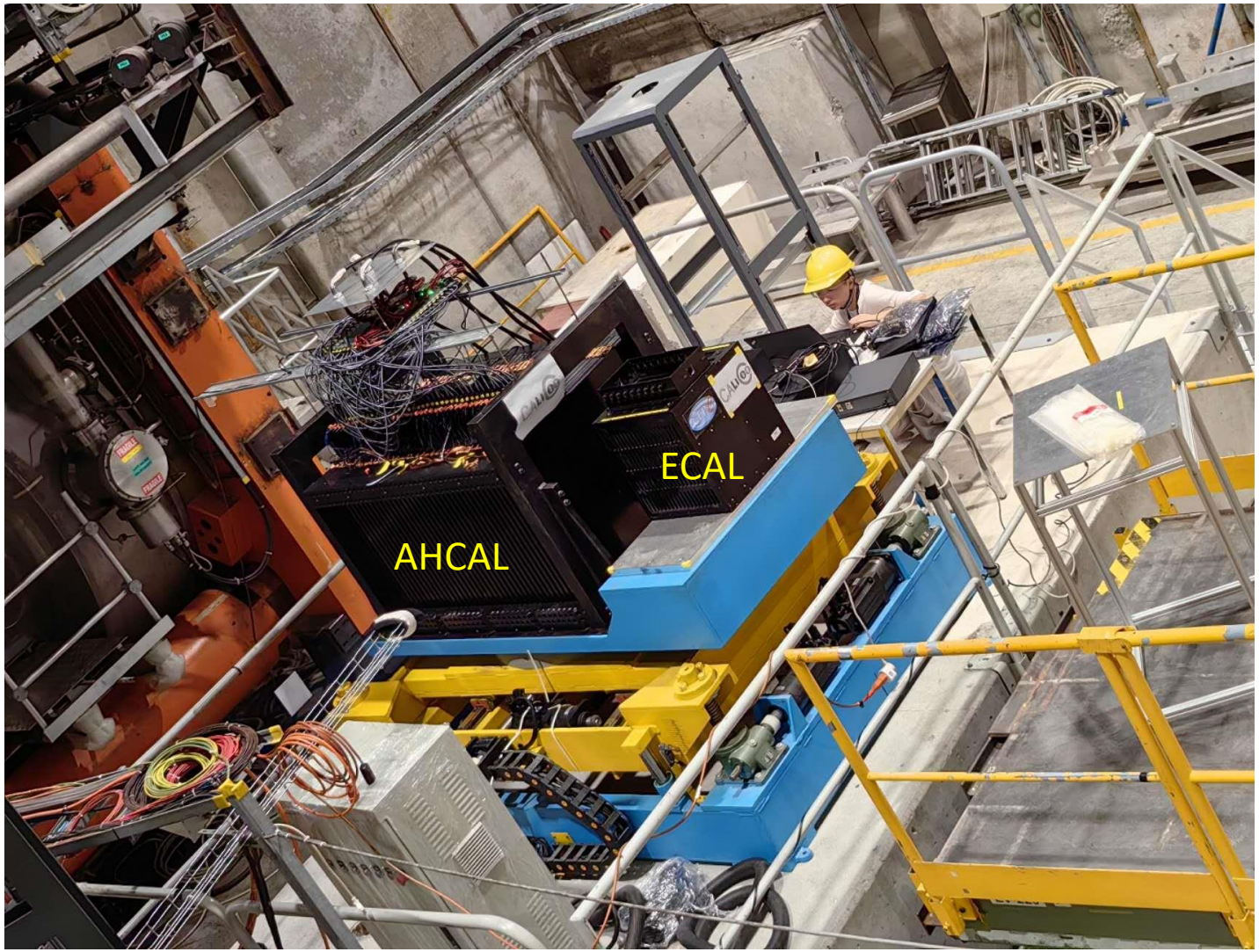








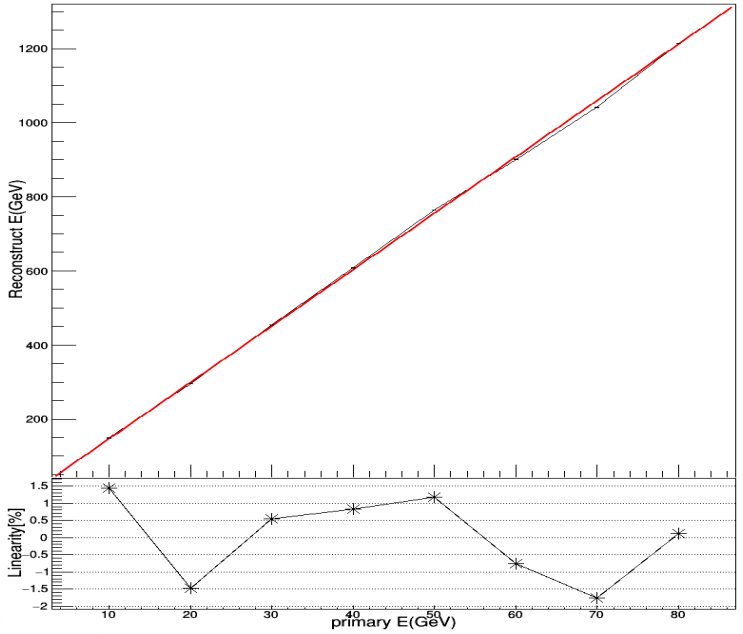
ECAL & AHCAL Beam Test

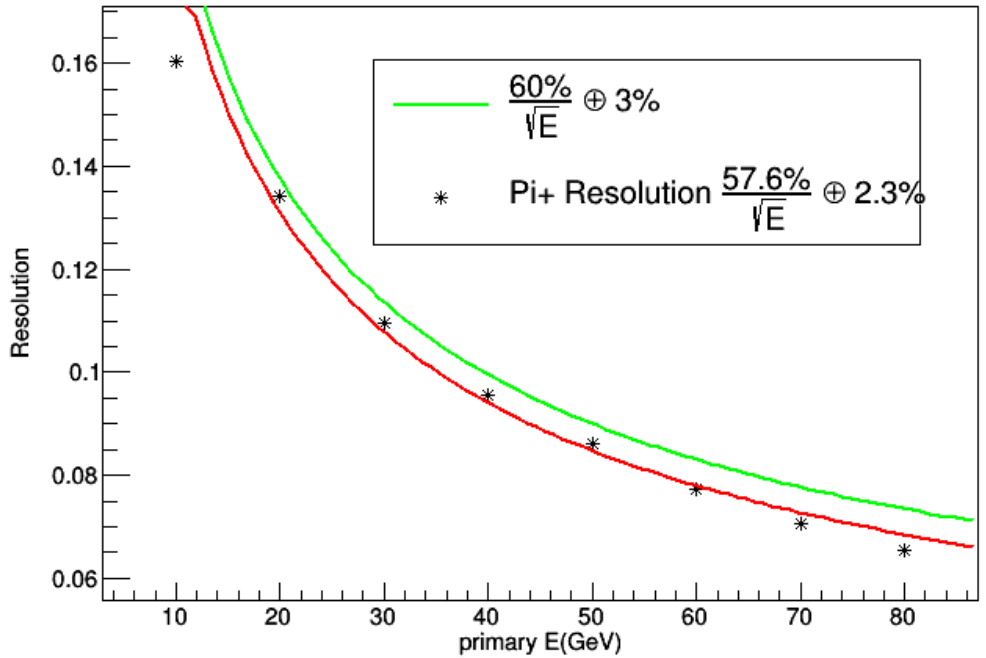


ECAL & AHCAL Beam Test

- Energy linearity better than 2%
- Energy resolution is $\frac{57.6\%}{\sqrt{E}} \oplus 2.3\%$

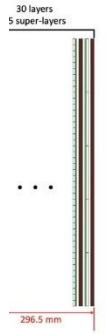
  10 – 80 GeV

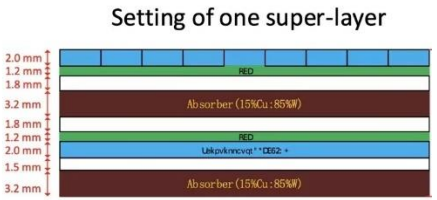




计算依据

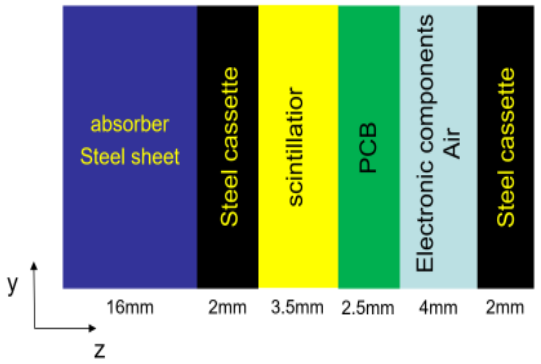
ECAL Barrel Inner radius R1 = 1.90m, Outer radius R2 = 2.14m, length L= 6.0m, Nlayers=30 Area of Barrel = 2*PI*[(R1+R2)/2]*L * NLayer = 2284.6 m2
ECAL Endcap Inner radius r1 = 0.35m, Outer radius r2 =2.14m, Nlayers=30 Area of Endcap = 2*PI*(r2*r2 – r1*r1) * NLayer = 840.2 m2





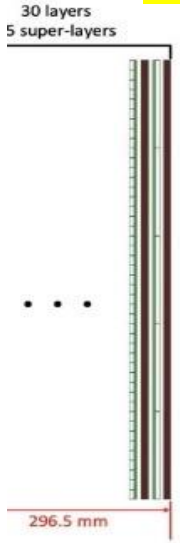
HCAL Barrel Inner radius R1=2.25 m, Outer radius R2=3.69m, length L= 6.7m, Nlayers=48, Area of Barrel = 2*PI*[(R1+R2)/2]*L * NLayer = 6001.4 m2

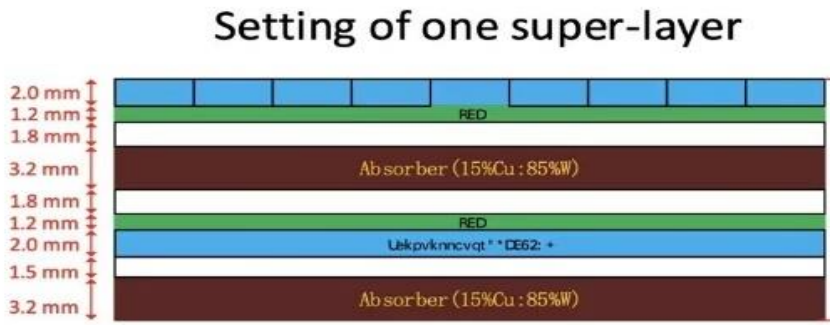
HCAL Endcap Inner radius r1 = 0.4m, Outer radius r2 =3.69m, Nlayers=48, Area of Endcap = 2*PI*(r2*r2 – r1*r1) * NLayer = 4058.3 m2



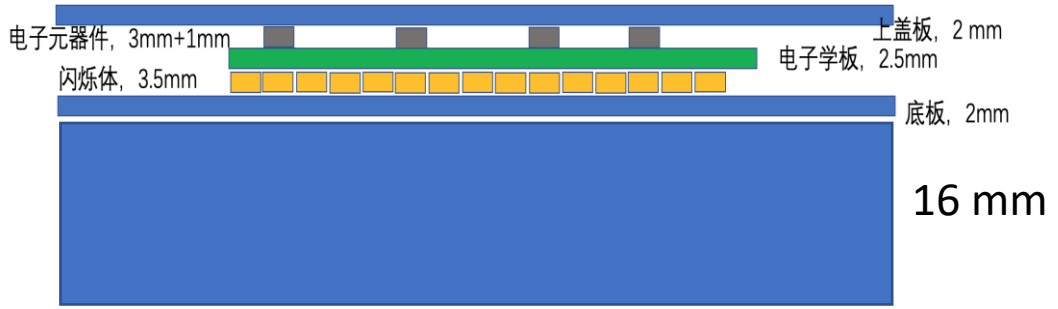
样机

- ECAL
  - 闪烁体：2 mm
  - PCB：1.2 mm
  - 元器件：1.8 mm
  - 吸收体：3.2 mm
  - 冗余：0.75mm
- 单层：8.95 mm
- 后面尺寸估算：一层8.5 mm





- AHCAL
  - 闪烁体+ESR：3.5 mm
  - PCB：2.5 mm
  - 元器件：3 mm
  - 吸收体：20 mm
  - 冗余：1 mm
- 单层：30 mm



HCAL options for ILC: based on ILC TDR Volume 4

Components	ILD-SDHCAL: RPC + steel	ILD-AHCAL: Scintillator + Steel
Electronics Components	3 mm for PCB + components	2.4 mm for PCB + components
Readout PCB		
Scintillator Tiles	3mm RPC	3mm scintillator + wrapping
Sensitive Layer	6 mm	5.4 mm
Absorber Layer	20 mm	20 mm
One HCAL Layer	26 mm	25.4 mm
40-layer HCAL (*note: no such design in ILD; comparison only*)	1040 mm	1016mm
48-layer HCAL	1248mm	1220mm

Performance Summary

Items	Priority	Results / Status		Remarks
Boson Mass Resolution	A	1.97% （H->γγ） 3.73% （ννH->ννgg）		BMR < 4%
Intrinsic EM/hadronic energy resolution	A	$15.3\%/\sqrt{E}\oplus 0.9\%$; $48\%/\sqrt{E}\oplus 3\%$	$57.6\%/\sqrt{E}\oplus 2.3\%$	
Separation power				gamma/gamma, gamma/hadron, hadron/hadron
Lepton ID in jets				
Timing capability				
π^0 reconstruction				
Pile-up at Z-pole				

- Priority/importance for performance requirements: (A) must-have; (B) plus; (C) not essential

ECAL Cost Summary

Parameter Name	Barrel	Endcaps (x2)	Sum
Inner Radius for ECAL	1900 mm	350 mm	NA
Length for barrel; Outer radius for endcap	5900 mm	2200mm （1900 mm + $24X_0$）； Sc-ECAL：2155mm 16分区边沿：2197.2	NA
Longitudinal Depth	2155 mm		NA
Modularity	#modules in phi, #rings along Z	Assuming ideal geometry if no design?	NA
Material Volume (m^3)	6.76	2.56	9.32m3 159.8M
Readout channels	21.25M	8.04M	29.29M
Power dissipation (kW)	148.75	56.28	205.1
Cost: sensitive materials (Yuan)	286.9 M	108.5M	394.5M
Cost: electronics	318.8 M	120.6 M	439.4 M
Total Cost			0.994 B

闪烁体+ESR：2.5mm
PCB+Comp：3.0mm
W-Cu：3.0mm
一层：8.5mm
30层：255mm

闪烁体：3.5元/channel
SiPM: 10 元/片
电子学：15 元/channel
W：123$, 886 元/kg

AHCAL Cost Summary

Parameter Name	Barrel	Endcaps (x2)	Sum
Inner Radius for HCAL	2250 mm	400 mm	NA
Length for barrel; Outer radius for endcap*	6600 mm	3690mm	NA
Longitudinal Depth	$6\lambda_I$, 1440 mm, edge 3762.3 mm		NA
Modularity	#modules in phi, #rings along Z	Assuming any ideal geometry if no design?	NA
Material Volume (m^3)	124.4	85.2	209.6m3 （1647.5吨） 92.3 M
Readout channels	3.65M	2.50 M	6.15
Power dissipation (kW)	25.5	17.5	43.0
Cost: sensitive materials(Yuan)	63.9 M	43.8 M	107.7 M
Cost: electronics	54.8 M	37.5 M	92.3M
Total Cost			292.3 M

闪烁体+ESR：3.5mm
PCB+Comp：5.5 mm
Fe：21 mm
一层：30mm
48层：1440mm

闪烁体：7.5元/channel
SiPM: 10元/片
Ele：15元/channel
Fe：5.6万元/吨

Technical readiness level

- Status and plans of simulation studies and R&D (a table template)
- Person power

Category	Status	Design 1	Other Alternative Design (if any)
Technical Readiness Level	Full Simulation (system level)		
	Full Simulation (module level)		
	Prototyping R&D (common)		
	Prototyping R&D (modules, units)		

ECAL and AHCAL

- ECAL (Scintillator + SiPM, Barrel 2323 + Endcap 840 = 3163 m2)
  - P(inside layer) ~ 3.163^7 (channels) * 7mW/ch(SPIROC) = 221.4 kW (full load)
- P(interface) ~ 9W /DIF/m2 * 3163m2 = 28.5 kW
- P(total) ~ 250 kW

- AHCAL (Scintillator + SiPM, Barrel 5609.2 + Endcap 4045.3 = 9654.5m2)
- P(inside layer) ~ 6.0341e6 (channels) * 7mW/ch (SPIROC) = 42.24 kW
- P(interface) ~ 9W /DIF/m2 * 9654.5m2 = 86.9 kW
- P(total) ~ 129.14 kW