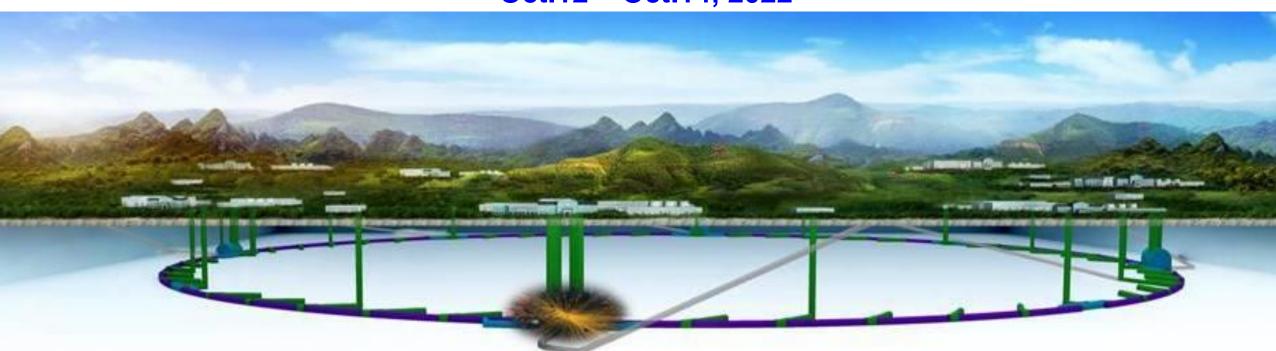
Status of the CEPC AHCAL Prototype

Haijun Yang (SJTU & TDLI)
(for the CEPC AHCAL Group: USTC, IHEP, SJTU, TDLI, SIC)

The CALICE Collaboration Meeting
IJCLab/Orsay and LLR/Palaiseau, France
Oct.12 – Oct.14, 2022





Outline



- Introduction of AHCAL
- **AHCAL** Design and Optimization
- Scintillator and SiPM
- **A Readout Electronics and Mechanics**
- Prototype Assembly and Test
- Preparation for TB at CERN
- **Summary**



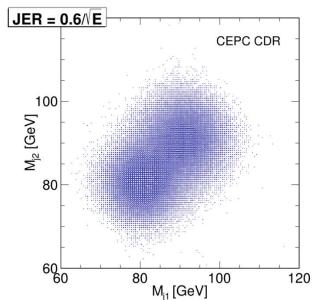
Introduction

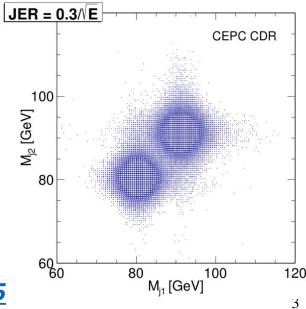


CEPC as Higgs/W/Z boson factories

- H/W/Z decay into hadronic final states are dominant, it is crucial to design high granularity calorimetry system (ECAL and HCAL) to separate them.
- **A** Required Jet Energy Resolution σ /E: 3-4% at 100 GeV

Physics process	Measurands	Detector subsystem	Performance requirement		
$ZH,Z\to e^+e^-,\mu^+\mu^-$ $H\to \mu^+\mu^-$	$m_H, \sigma(ZH) \ { m BR}(H o \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\text{GeV}) \sin^{3/2} \theta}$		
$H o bar{b}/car{c}/gg$	${ m BR}(H o bar b/car c/gg)$	Vertex	$egin{aligned} \sigma_{r\phi} = \ 5 \oplus rac{10}{p(ext{GeV}) imes \sin^{3/2} heta} (ext{ } \mu ext{m}) \end{aligned}$		
$H o qar q, WW^*, ZZ^*$	${ m BR}(H o qar q,WW^*,ZZ^*)$	ECAL HCAL	$\sigma_E^{{f Jet}}/E = \ 3 \sim 4\%$ at $100~{ m GeV}$		
$H o \gamma \gamma$	${\rm BR}(H\to\gamma\gamma)$	ECAL	$\Delta E/E = rac{0.20}{\sqrt{E({ m GeV})}} \oplus 0.01$		





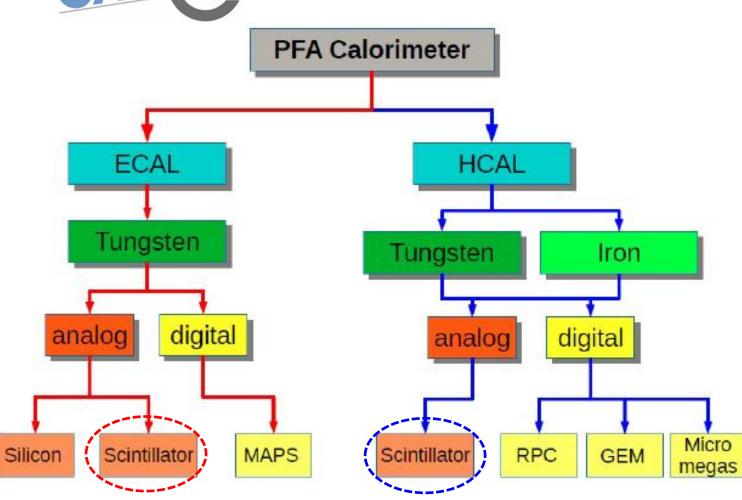


Introduction





https://twiki.cern.ch/twiki/bin/view/CALICE/





ECAL: Scintillator+SiPM See Yunlong's talk

AHCAL: Scintillator+SiPM



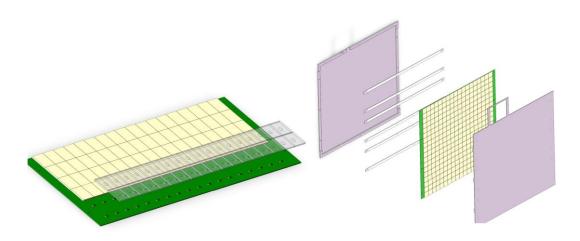
AHCAL Prototype based on Scint+SiPM+Iron

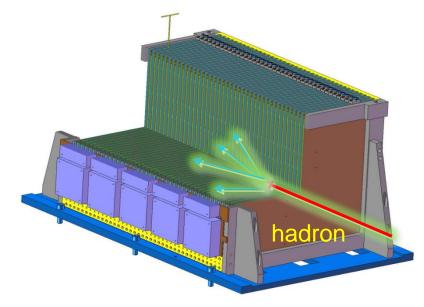


❖ Sampling Calorimeter

- 40 layers
- Each layer: 72 cm×72 cm
- * Absorber
 - Iron, 2 cm thickness / layer
- **Sensitive Detector**
 - Scintillator + SiPM
 - Cell size: 40 mm × 40 mm × 3mm
 - SiPM: HPK S14160-1315 and NDL-22-1515
- Electronics with analog readout
 - SPIROC2E ASIC Chip (36-ch)
 - 12960 channels

AHCAL Structure



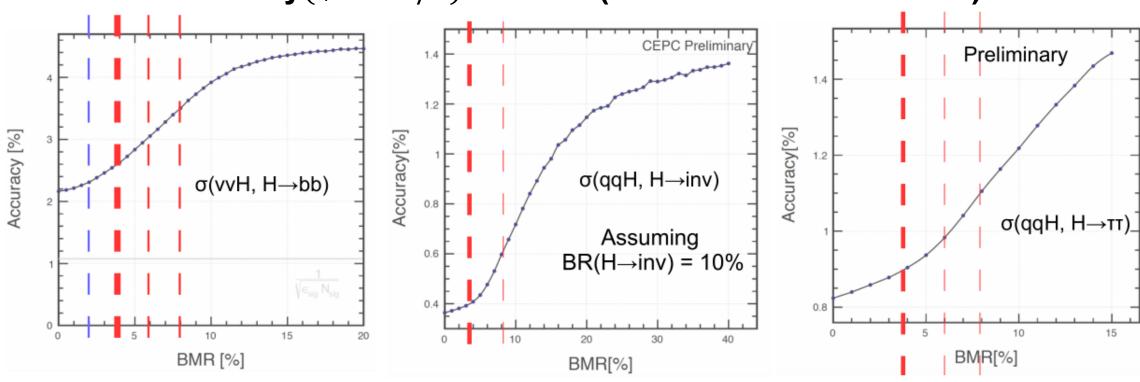




Design and Optimization



Accuracy $(\sqrt{S+B}/S)$ vs BMR (Boson Mass Resolution)



S:
$$e^+e^- \rightarrow ZH, Z \rightarrow \nu\bar{\nu}$$

B:
$$e^+e^- \rightarrow \nu \bar{\nu}H|W$$
 fusion

S:
$$e^+e^- \rightarrow ZH$$

B:
$$e^+e^- \rightarrow ZZ$$

S:
$$e^+e^- \rightarrow ZH$$

B:
$$e^+e^- \rightarrow ZZ$$



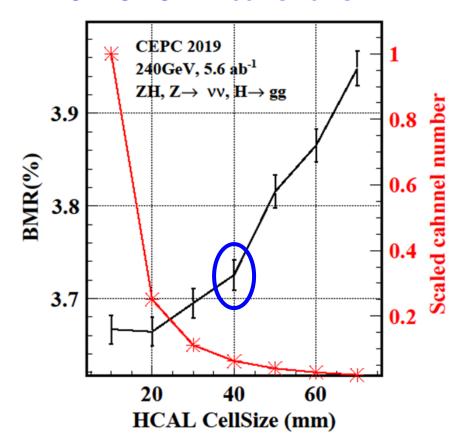


Optimization of AHCAL: Cell Size

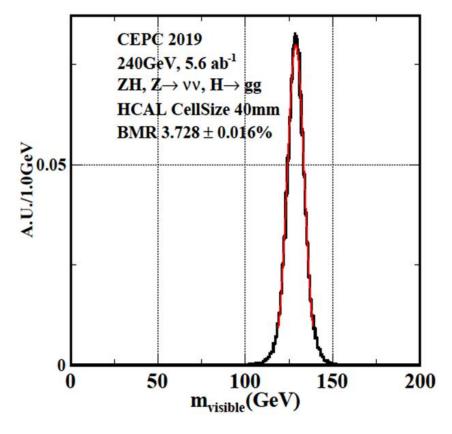


- **The Hgg channel** $(e^+e^- \to ZH, Z \to \nu \overline{\nu}, H \to gg)$ is used for optimization
- ightharpoonup The Higgs mass ($m_{visible}$) is calculated by summing up the 4-momentum of all visible particles in the detector

CEPC ACHAL cell size vs BMR



Cell size 40mm: BMR

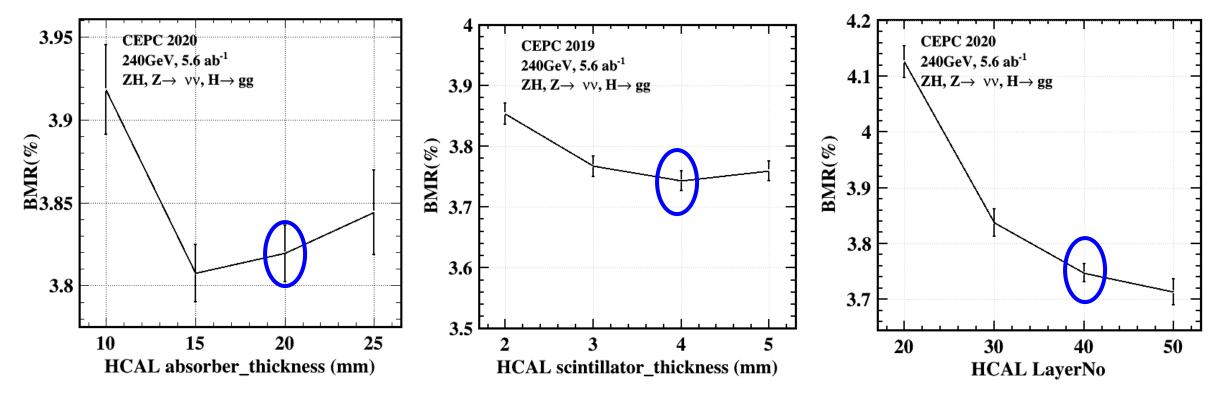




Optimization of AHCAL: Thickness & No. of Layers



- ❖ The BMR vs absorber thickness → baseline: 20mm
- ❖ The BMR vs scintillator thickness → baseline: 4mm
- ❖ The BMR vs number of layers → baseline: 40 layers



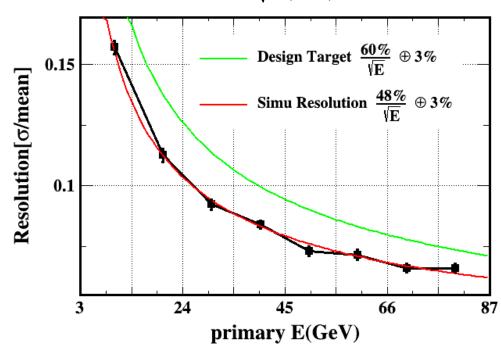
Absorber Thickness

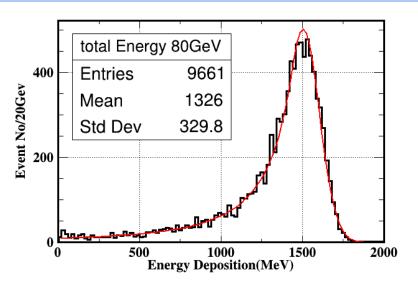
Scintillator Thickness

Number of Layers

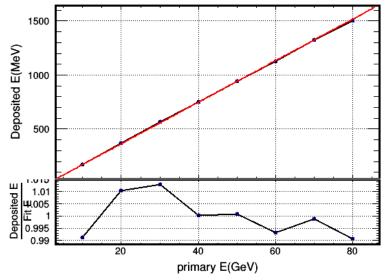


- **→** Design Parameters of the AHCAL Prototype
 - \circ 40 layers, each layer $72 \times 72 \text{ cm}^2$
 - Steel absorber: 20 mm
 - \circ Scintillator size: $40 \times 40 \times 3 \ mm^3$
- \rightarrow $K_{\rm L}$ Performance of the AHCAL Prototype
 - \circ Energy Linearity: $\pm 1\%$
 - Energy Resolution: $\frac{48\%}{\sqrt{E(GeV)}} \oplus 3\%$





Energy deposition of 80 GeV $K_{ m L}$



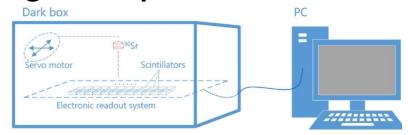
Energy linearity ($\pm 1\%$)

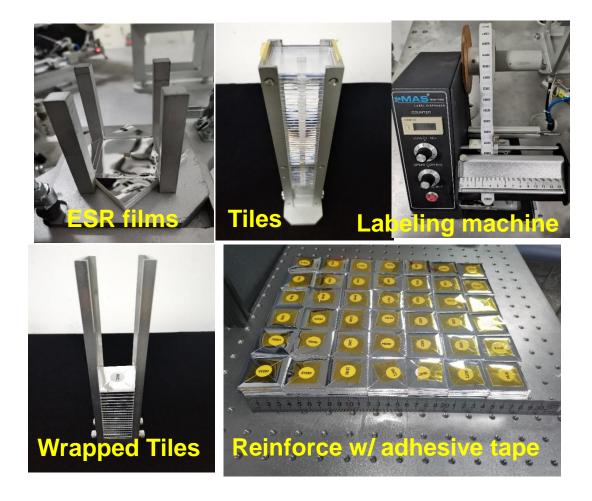


Scintillators



- **❖** >15K scintillators are produced with injection molding technique
- **❖** It is wrapped automatically with ESR films
- Using scintillator batch test platform (with Sr-90)



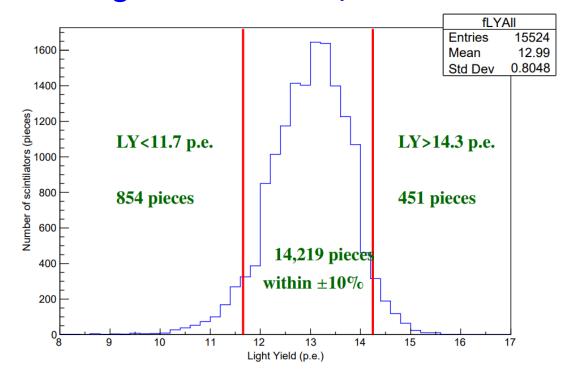




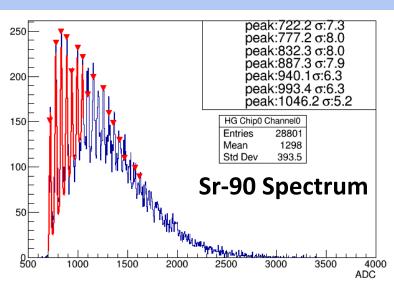
Scintillators



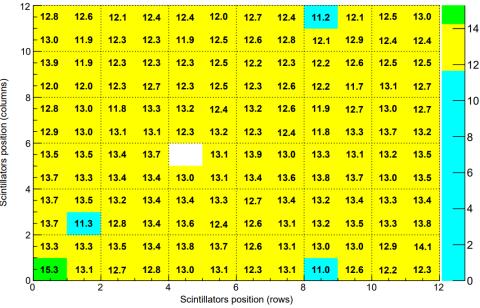
- ❖The batch test system
 - HPK 13360-1325PE SiPM + SPIROC readout
 - 144 channels / batch
 - The light yield is fitted by landau-gauss function
- → 14219 out of 15524 scintillators are within 10% of Light Yield window, selected for construction.



Light yield for all scintillators



Light yield for one batch of scintillators





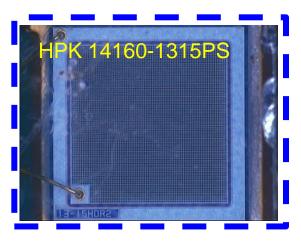
SiPM



* HPK-SiPM

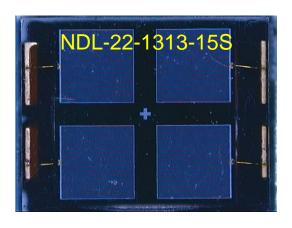
- Low PDE, dark rate and crosstalk
- High breakdown voltage
- Better quality control
- $_{\circ}$ 38 layers (38 \times 324 = 12312)





* NDL-SiPM

- High PDE, dark rate and crosstalk
- Low breakdown voltage
- **Low price**
- $5 \text{ layers } (5 \times 324 = 1620)$



Company	HP	NDL		
Туре	13360-1325PE	14160-1315PS	22-1313-15S	
Light output [p.e.]	13	17	20	
Crosstalk[%]	1.59	1.17	4.4	
Dark Counts [kHz]	120	290	550	
Breakdown[V]	53	38	27.5	

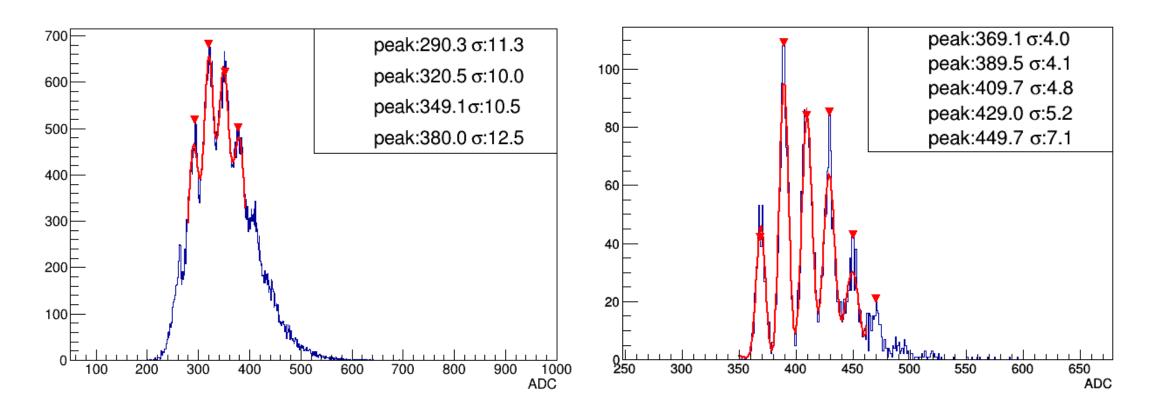


SiPM



❖LED calibration

- Both SiPMs can separate single photon
- ADC value of a single photon can be calibrated



LED spectrum for NDL (left) and HPK (right) SiPMs



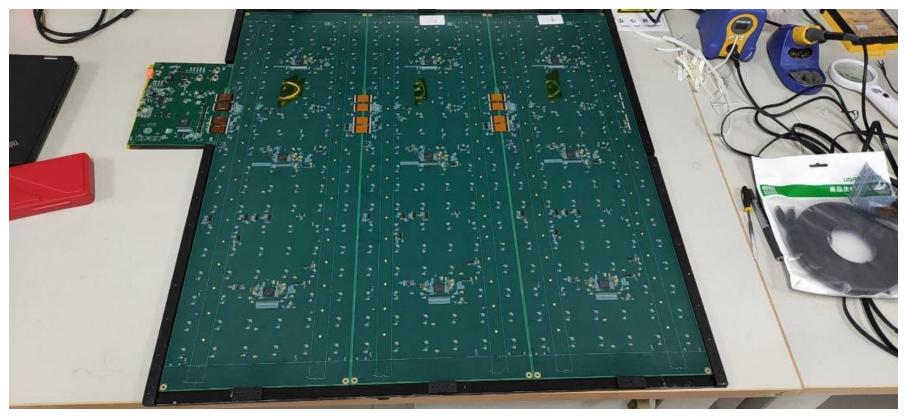
Electronics



❖ Each layer is composed of 3 HBUs and 1 DIF

- Each layer has 324 SiPMs, hence has 324 channels
- o Each SiPM has a LED side by side for calibration
- The 324 channels are readout by 9 SPIROC chips
- **O There are 48 temperature sensors on each layer**







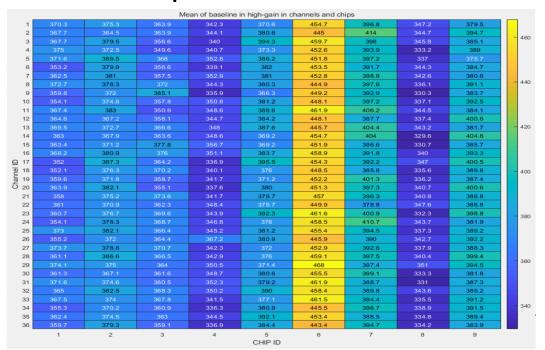
Electronics

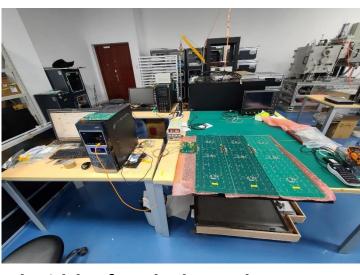


❖ The HBUs after welding were tested

- Noise of each channel
- DAC Calibration
- LED calibration for SiPM
- Temperature sensors response
- Force mode and self trigger Mode response

Pedestal position of each channel





Pedestal width of each channel

								-		
			RM	dS of baseline i	n high-gain in c	hannels and ch	ips			
1	4.184	4.463	5.353	6.146	4.211	4.126	3.838	3.691	3.259	
ul 2	4.363	6.663	3.545	3.445	4.68	6.976	3.792	3.545	3.753	П
3	3.245	4.647	3.441	3.844	3.649	7.066	4.036	3.363	3.531	П
4	3.925	6.104	8.306	3.242	3.67	5.804	7.423	5.958	3.57	П
5	3.552	3.983	3.093	3.197	4.331	4.242	5.879	4.761	3.549	П
6	3.045	3.684	3.057	3.364	5.933	5.44	6.197	3.979	3.524	П
7	3.173	3.231	7.095	4.411	6.225	4.992	4.018	3.74	3.591	П
8	3.37	9.991	3.649	3.887	3.807	4.847	4.615	3.162	4.136	П
9	3.343	3.233	3.737	3.78	6.137	8.094	4.998	3.642	3.955	П
10	6.404	3.623	3.947	3.732	4.243	4.423	4.163	3.876	3.742	П
11	3.256	4.173	3.707	3.661	5.62	4.342	4.414	4.163	4.203	
12	3.188	3.765	2.986	5.381	3.554	5.405	3.723	3.163	3.641	
13	3.213	3.991	3.077	3.484	6.28	4.77	3.626	3.167	3.798	
14	5.054	5.16	3.876	4.147	5.626		5.154	3.374	3.87	Ш
15	5.606	4.032	3.526		3.586	4.552	4.214	3.567	3.583	Ш
16	3.105	3.364	3.096	3.891	5.718	4.236	4.273	3.173	3.616	Ш
17	8.248	4.182	3.249		4.056		3.656	4.255	4.092	ш
18	3.575	3.635	5.706	7.1	4.561		3.468	3.304	5.55	П
19	3.449	5.516	3.15	3.653	3.93		5.092	3.295	3.553	П
18	5.747	3.624	3.676	5.059	4.372	5.71	3.758	3.662	3.837	ш
21	3.441	3.597	4.744	3.841	4.04	5.645	3.654	3.275	4.143	ш
22	3.527	4.048	3.22	3.447	4.923	4.367	3.491	5.677	4.045	П
23	3.263	3.79	5.218	4.755	4.447	4.261	3.877	3.885	3.637	П
24	3.118	3.427	3.241	5.087	6.174	4.207	6.836	3.321	4.715	П
25	3.425	5.547	3.73	6.125	3.714	4.439	3.399	3.166	4.72	П
26	6.066	4.127	3.186	3.436	6.658	5.063	4.408	3.728	3.81	ш
27	3.284	4.06	3.615	3.413	5.351	4.602	3.617	3,292	5,142	П
28	4.006	3.454	3,139	3.628	3.619	4.206	3.62	3.566	3.935	П
29	3.218	5.642	3.176	3.412	4.981	6.702	5.67	3.431	6.142	П
30	3.222	3.556	3.337	3.407	3.935	4.062	3.597	5.119	3.513	П
31	3.966	6.218	5.306	4.875	6.892	4.329	4.095	3.313	5.968	
32	3.179	3.37	5.607	3.896	4.262	4.295	4.803	5.869	4.187	
33	3.747	5.464	3.172	3.336	4.948	4.506	3.707	4.241	3.734	П
34	5.238	3.763	3.205	4.041	3.779	4.753	4.222	4.217	3.634	П
35	3.411	3.31	4.864	4.284	4.995	6.537	4.684	3.276	3.61	П
36	3.21	5.06	3.035	6.419	3.561	5.352	3.452	3.582	4.641	П
	1	2	3	4	5	6	7	8	9	•
					CHIP ID					



Electronics



- ❖ The temperature of single-layer HBU is ~ 1 °C higher than the room temperature, and it can keep stable for a long time
- **❖** With LED, SiPM p.e spectrum is visible
- **❖** High/low gain ratio of each channel is ~ 30 times

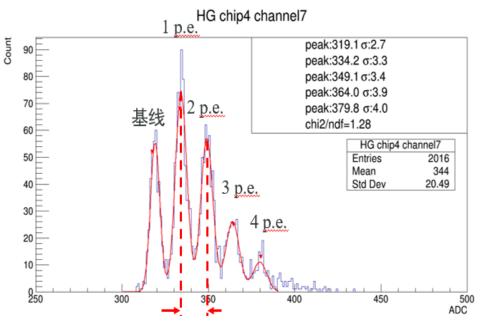
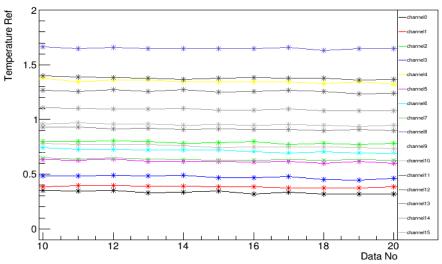
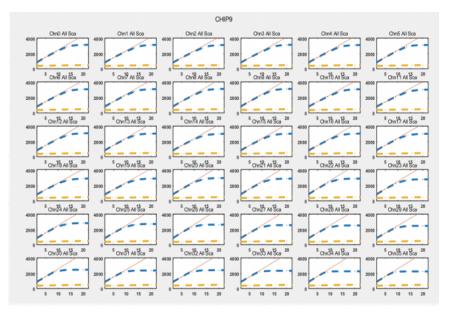


Photo-electron peak



Reference temperature



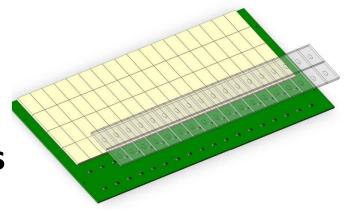
High/Low gain calibration



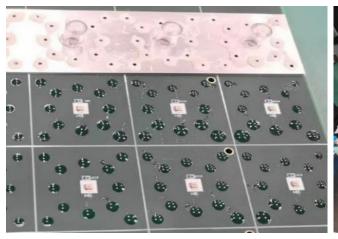
Assembly of Scintillator, SiPM and HBU

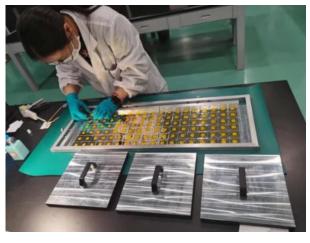


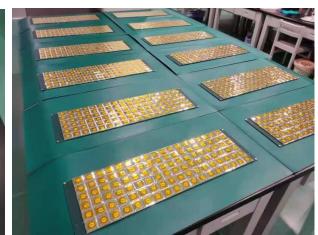
- **Assemble the scintillator on HBU**
 - Fix the scintillators on the HBU with glue
 - Press them with cover plate for solidification
- **❖** 38 layers with HPK and 5 layers with NDL SiPMs
- All assembly has completed in early August



Scintillators on HBU









Glue for Scintillators

Scintillators on HBU

HBU finished

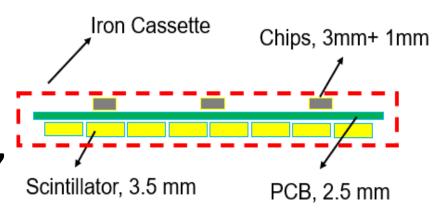
3 HBUs in 1 cassette



Mechanics: HBU Cassettes



- **♦ HBU cassettes: Size 76cm × 82cm & 14mm thick**
 - Up and bottom iron plate: 2mm each
 - Scintillator thickness: 3mm
 - HBU: 2mm PCB + 4mm electronic parts
- Choose iron as the cassette support material, it is considered as part of the absorber



HBU Cassette



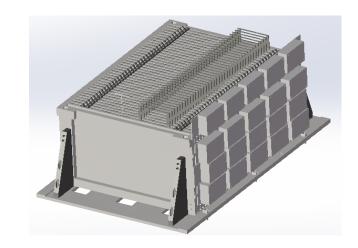


Assembly of AHCAL Prototype



❖The assembly of the AHCAL prototype

- Prototype structure based on cassettes (14mm)
- HBU cassette can be easily inserted into the gap between neighbor absorbers (14.5mm)







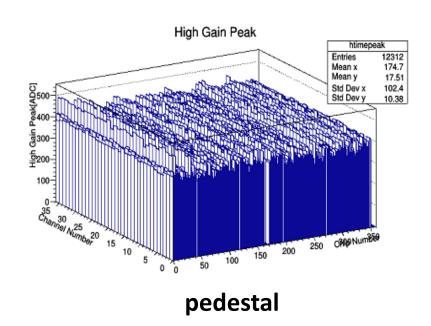


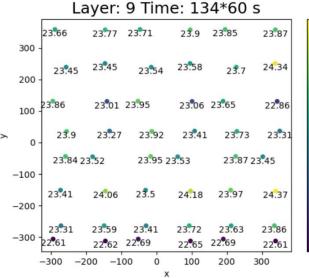
Cosmic Ray Test

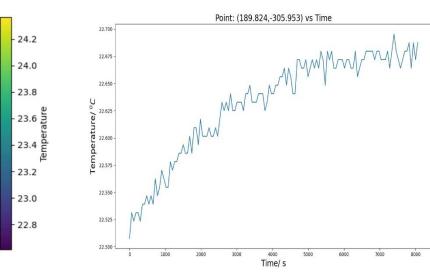


Cosmic Ray Test

- It was divided into two groups to carry out cosmic ray testing
- Preliminary results indicate it works well
- Temp. monitors (48/layer) show that HBU
 temp is ~2 °C higher than room temperature.







Temperature in one layer

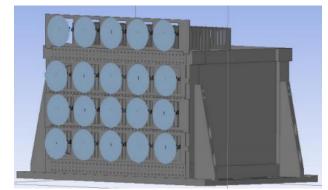
Temperature vs Time

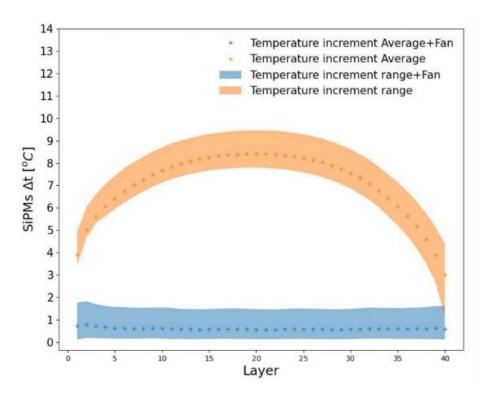


Temperature Simulation for AHCAL

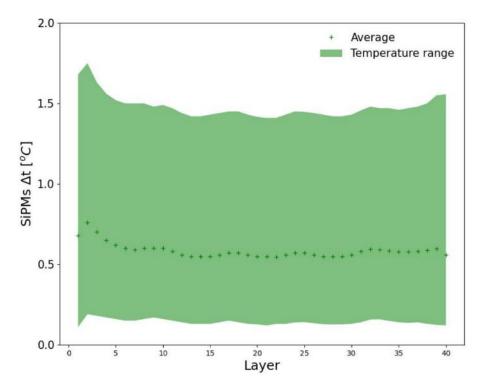


- Simulation has been done using ANSYS according to HBU design
- Heating sources per layer: ~ 5523mW + 2162mW (DIF)
- The SiPM's temperature with or without fan
- SiPM's temperature is quite stable with fan, $\Delta T < \sim 2^{\circ}C$









SiPM Temp with fan vs No. of layer

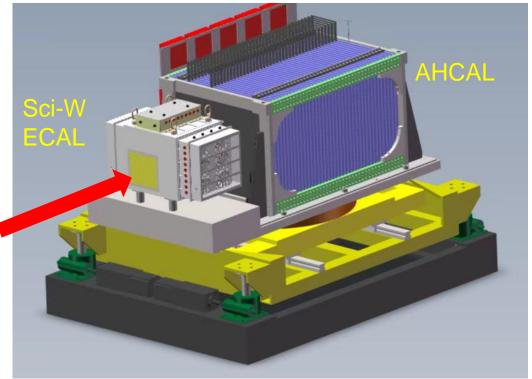


Preparation for Test Beam



- The adjustable platform is designed for Test Beam at CERN
 - The platform can support AHCAL and Sci-W ECAL prototypes at the same time
 - \circ Horizontal movement is ± 20 cm, vertical movement (up/down) is ± 15 cm







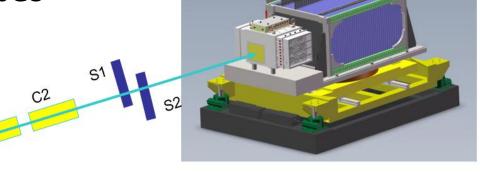
Trigger Logic Unit (TLU)

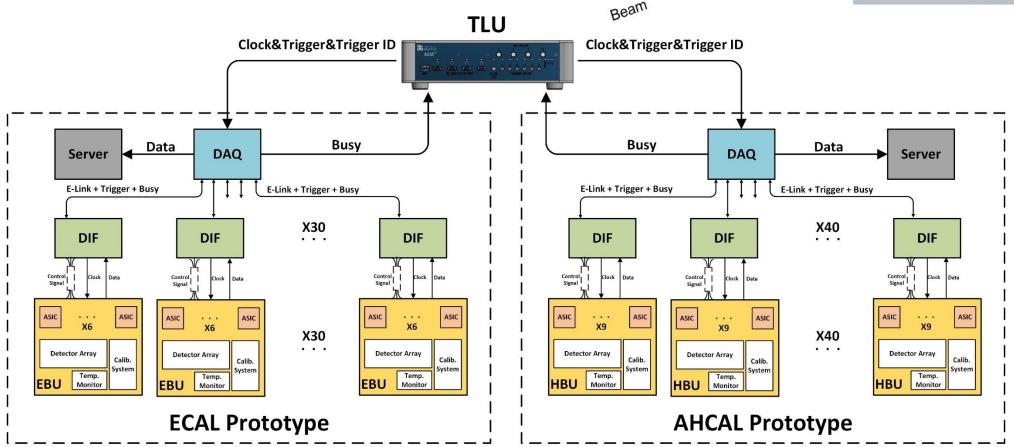


❖ DAQ system for ECAL and AHCAL Prototypes

ECAL has 30 DIFs, AHCAL has 40 DIFs

Using TLU to synchronize two systems





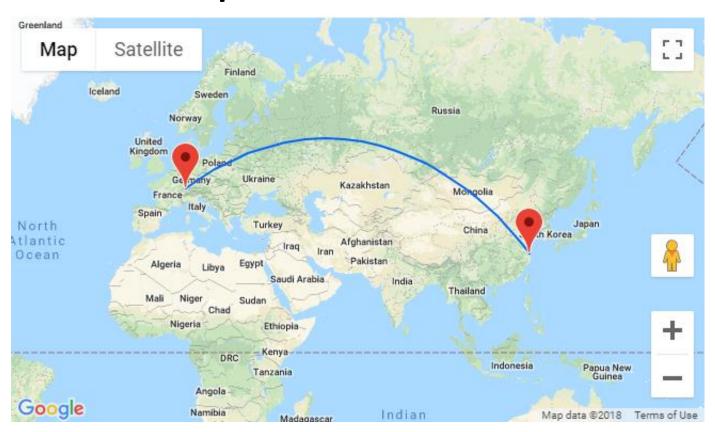


Preparation for Test Beam



❖ The AHCAL and ECAL prototypes are delivering from China to CERN

starting on Oct. 3, 2022, now arrived at Geneva airport.





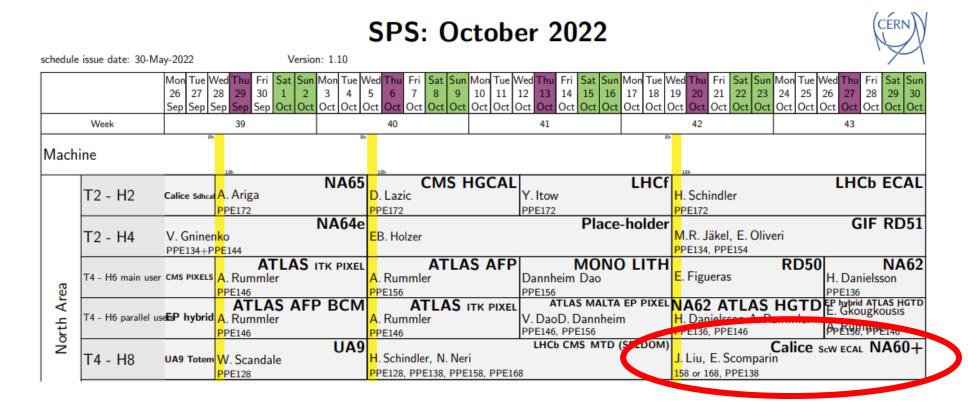




Preparation for Test Beam



- Two weeks of beam testing at SPS H8, PPE168 (Oct.19 Nov.2)
 - The H8 beam line is a high-energy, high-resolution secondary beam line.
 - Proton beam: up to 400 GeV/c
 - Secondary mixed hadron beams: 10-360 GeV/c.
 - \circ Electron beam: with purity (10 99 %), max. $\Delta p/p$ acceptance is 1.5%





Summary and Plan



- > AHCAL and ScW-ECAL prototypes are built and tested by cosmic ray events
- ➤ By using high energy hadrons, electrons and muons, we can make performance studies on AHCAL & Sci-W ECAL prototypes
- ➤ We are preparing for TB using CERN SPS H8 beamline between Oct. 19 and Nov. 2. Hope we have successful TB in coming weeks.

Please stay tuned, thanks !!!