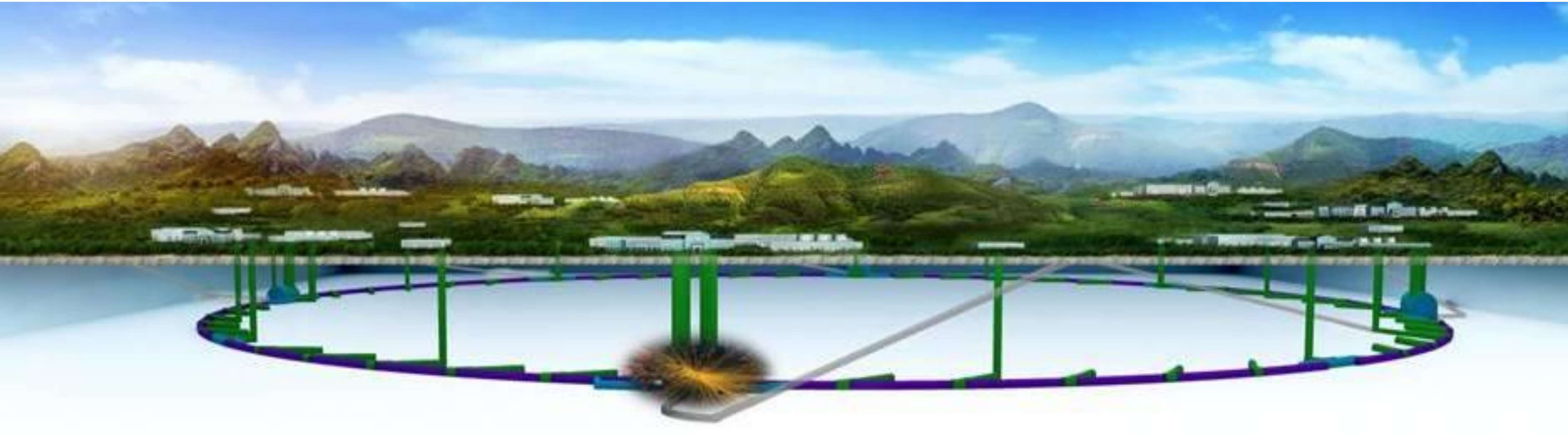
Status of the CEPC AHCAL Prototype

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
- ❖ Readout Electronics and Mechanics
- ❖ Prototype Assembly and Test
- ❖ Preparation for TB at CERN
- ❖ Summary

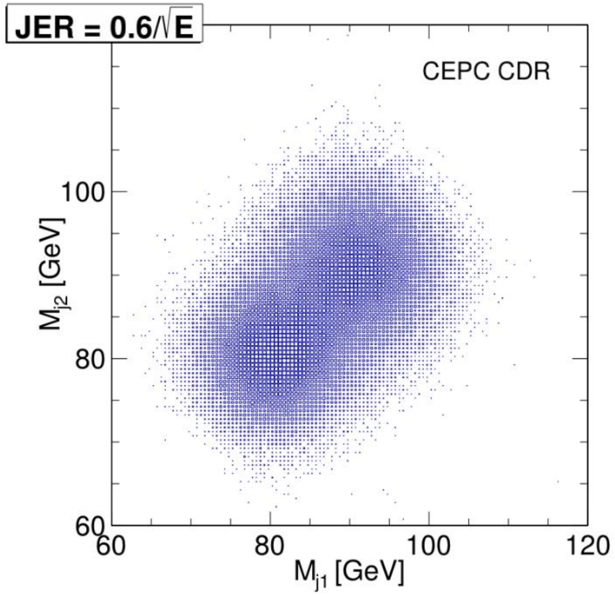
Introduction

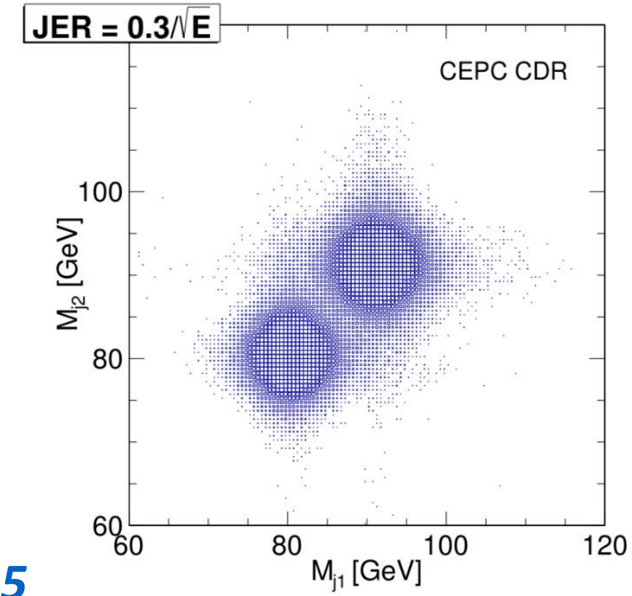
CEPC as Higgs/W/Z boson factories

- ❖ 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.
- ❖ Required Jet Energy Resolution σ/E: 3-4% at 100 GeV

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

Requirement of CEPC baseline detector

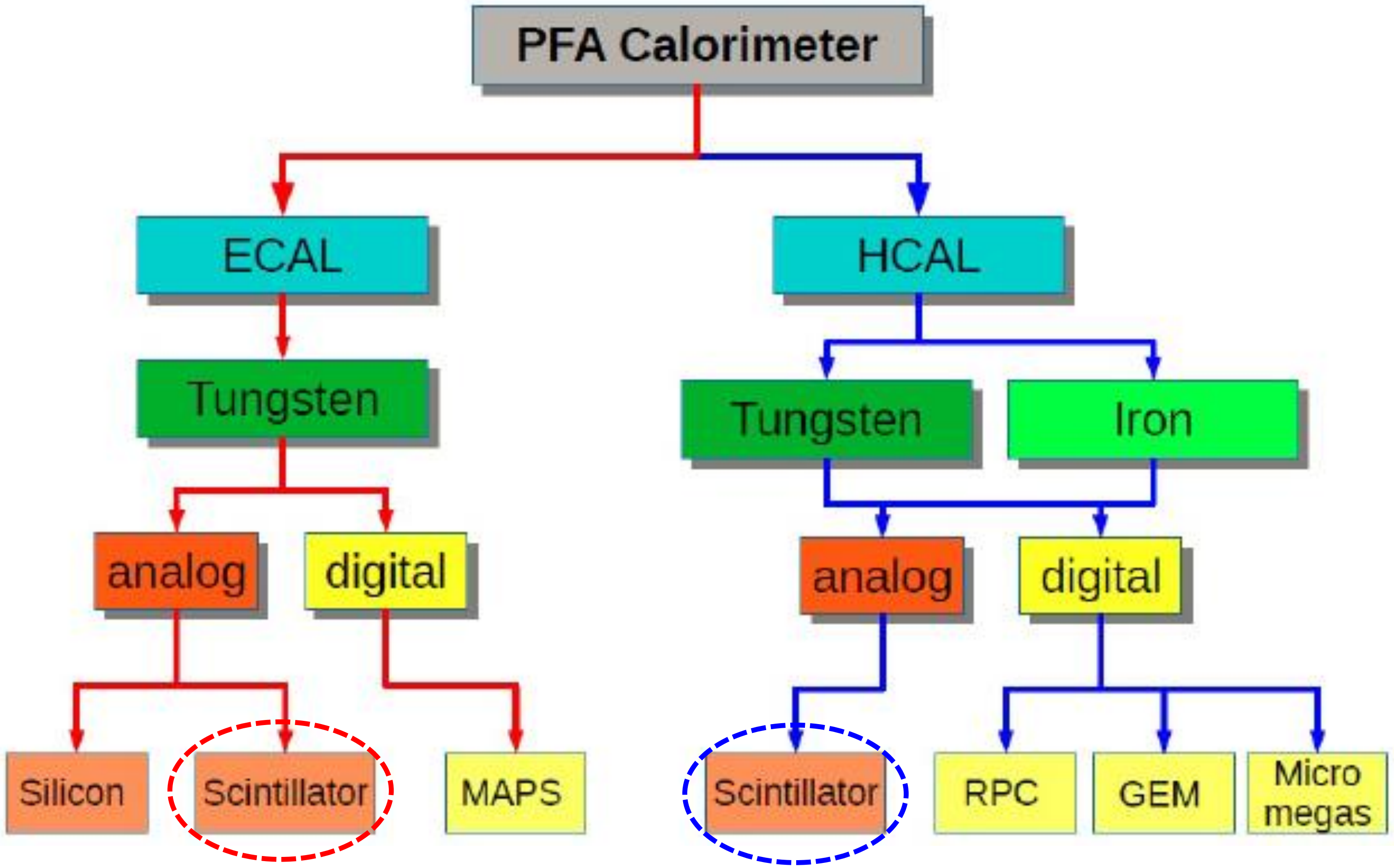




arXiv:1811.10545

Introduction

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



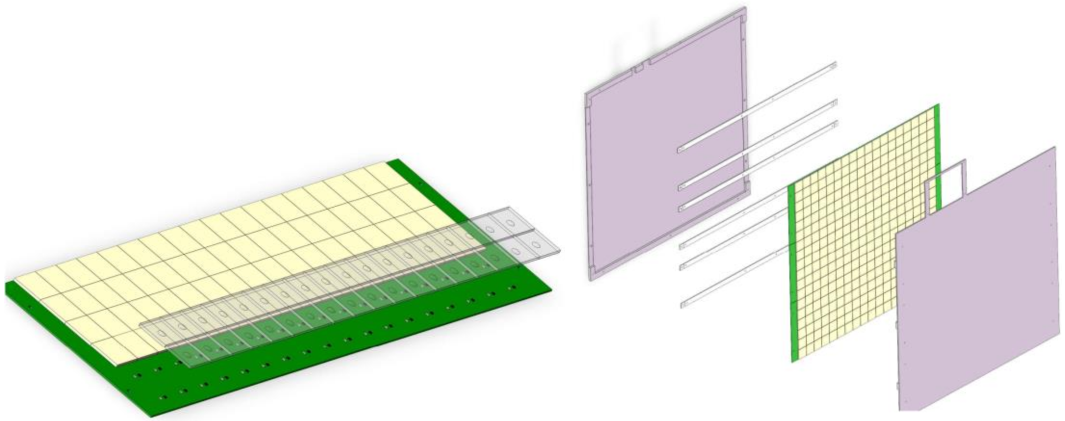
ECAL: Scintillator+SiPM
See Yunlong's talk

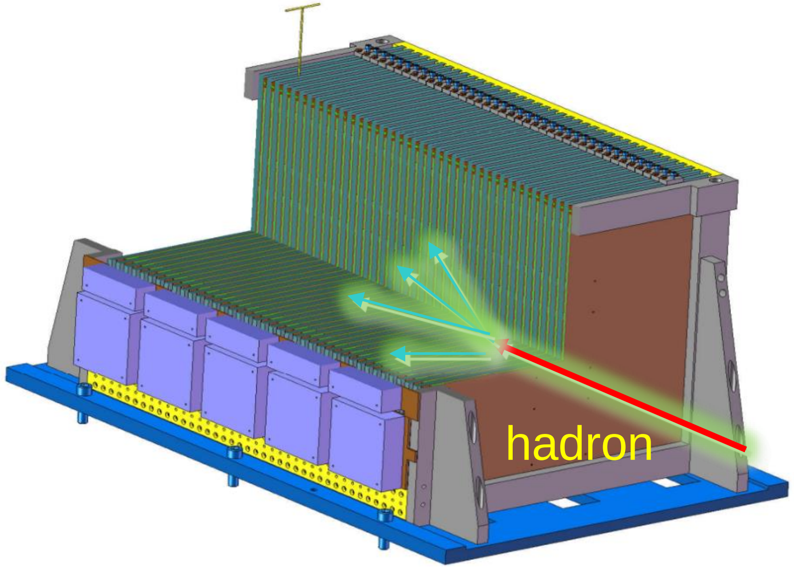
AHCAL: Scintillator+SiPM

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**

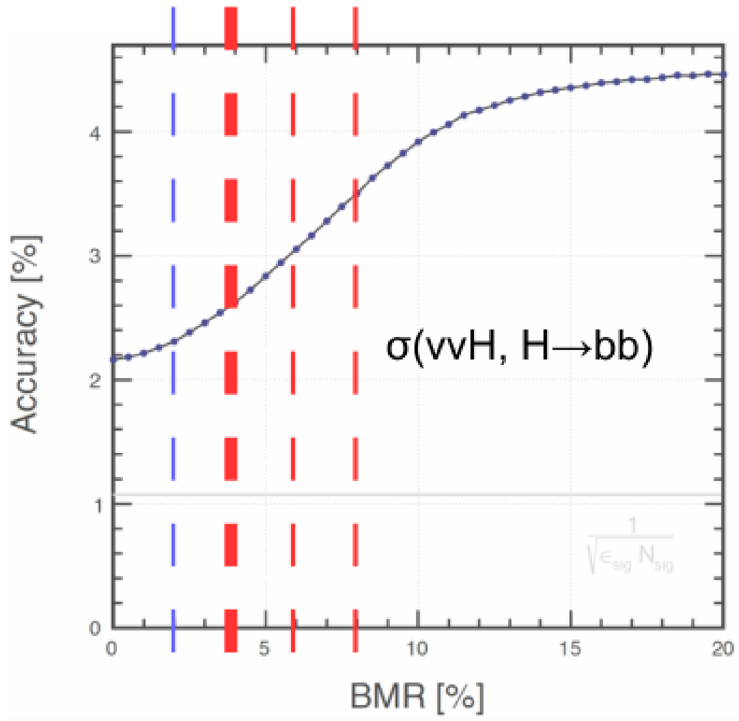
AHCAL Structure

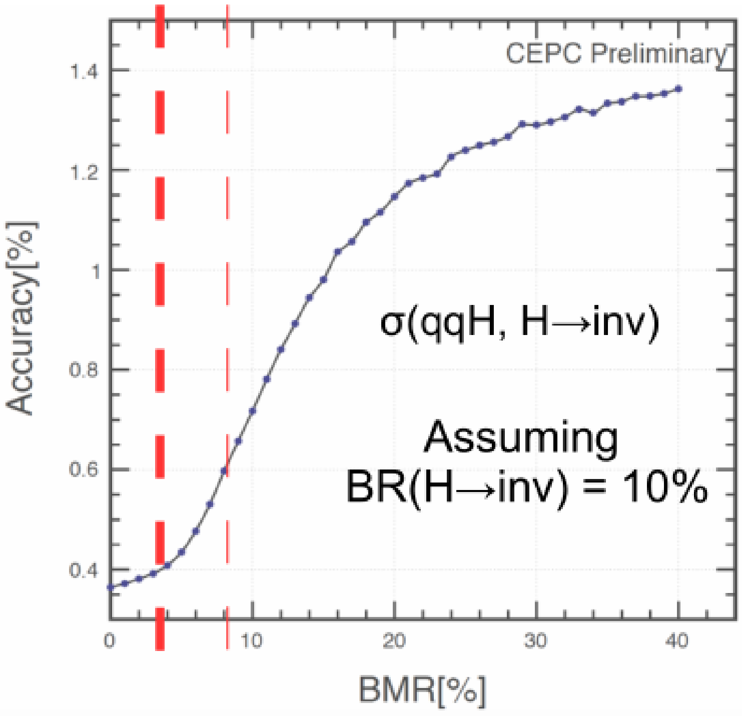


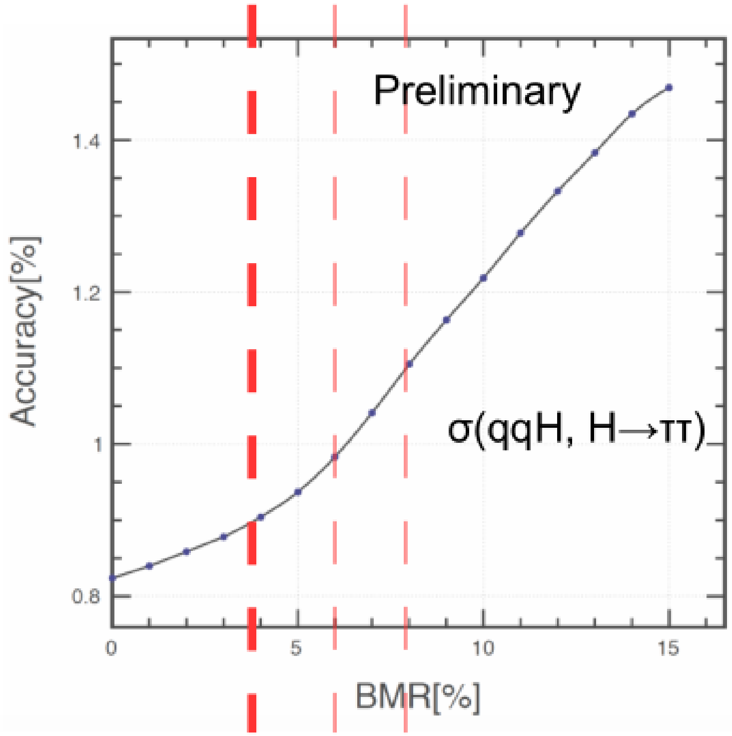


Design and Optimization

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







S: $e^+e^- \to ZH, Z \to \nu\bar{\nu}$
B: $e^+e^- \to \nu\bar{\nu}H|$W fusion

S: $e^+e^- \to ZH$
B: $e^+e^- \to ZZ$

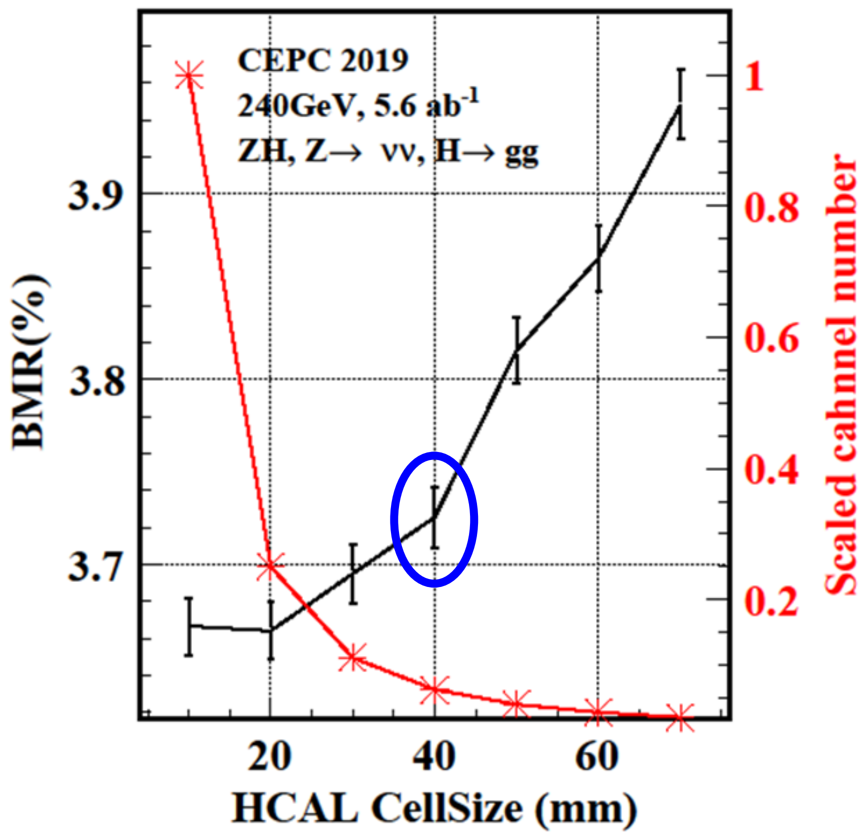
S: $e^+e^- \to ZH$
B: $e^+e^- \to ZZ$

➔ ~ 4 % BMR is required for CEPC detector to well separate the S/B.

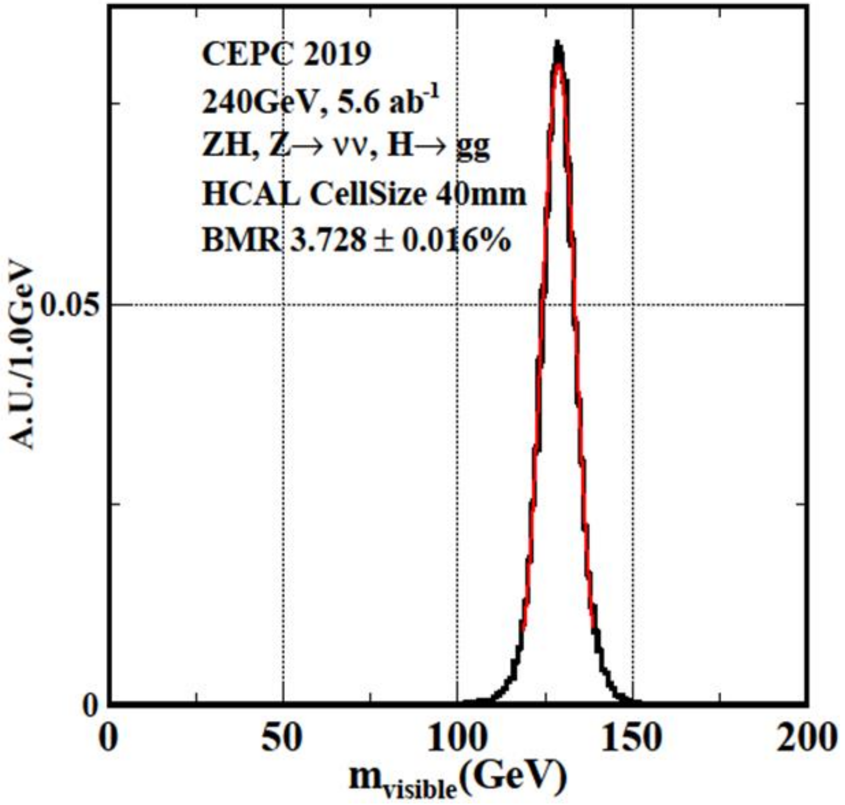
Optimization of AHCAL: Cell Size

- ❖ The Hgg channel ($e^+e^- \rightarrow ZH, Z \rightarrow \nu\bar{\nu}, H \rightarrow$gg) is used for optimization
- ❖ 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

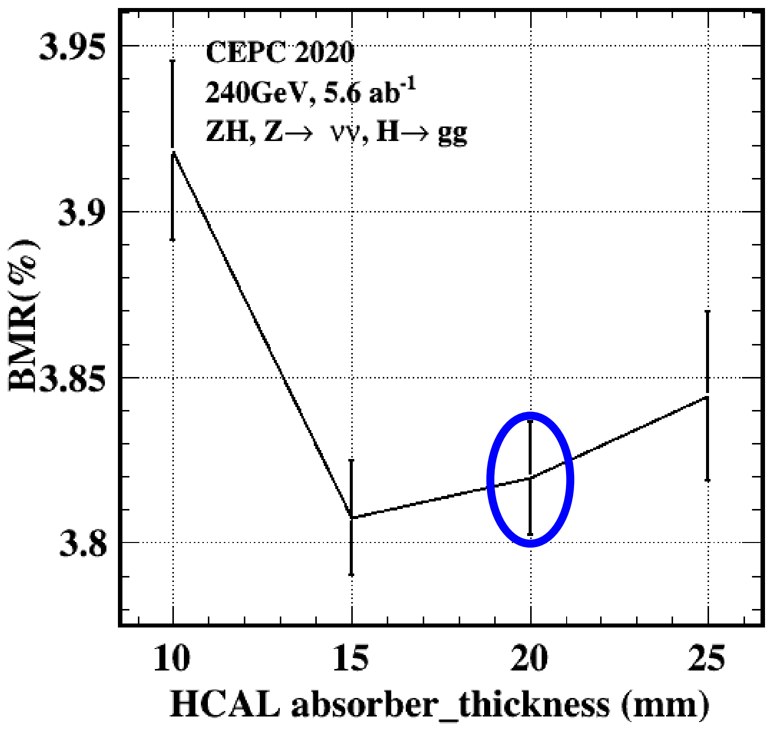


Cell size 40mm: BMR

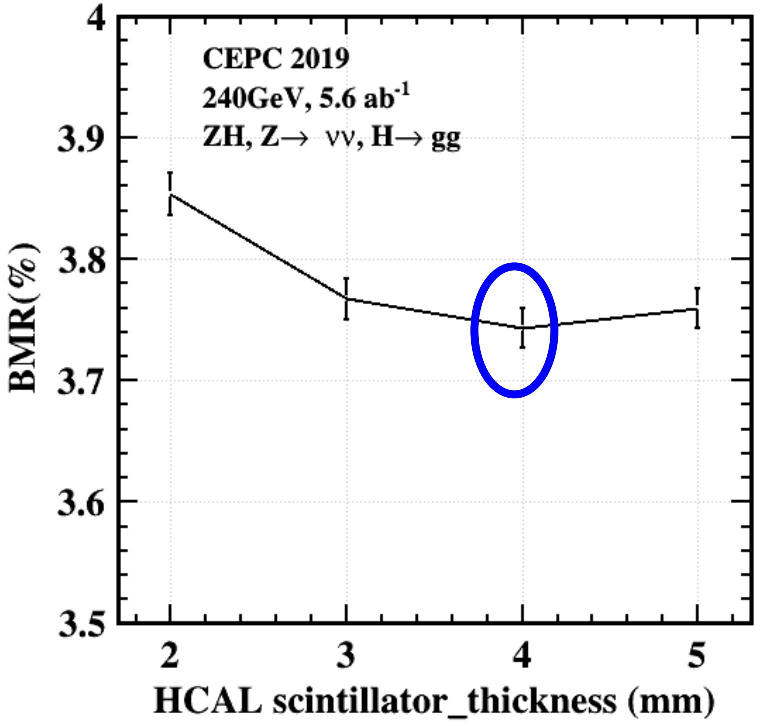


Optimization of AHCAL: Thickness & No. of Layers

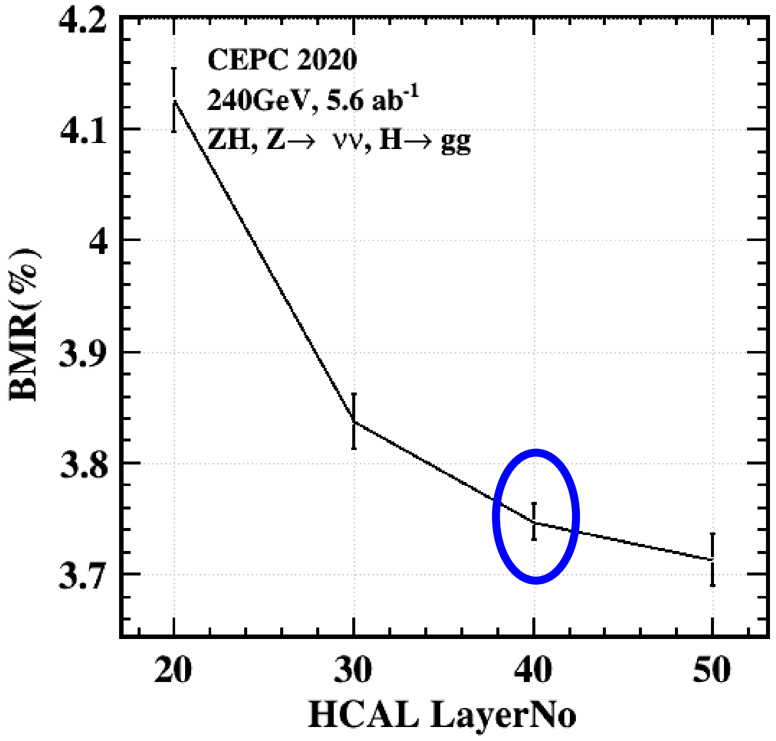
- ❖ The BMR vs absorber thickness ➔ baseline: 20mm
- ❖ The BMR vs scintillator thickness ➔ baseline: 4mm
- ❖ The BMR vs number of layers ➔ baseline: 40 layers



Absorber Thickness



Scintillator Thickness



Number of Layers

Design of AHCAL Prototype

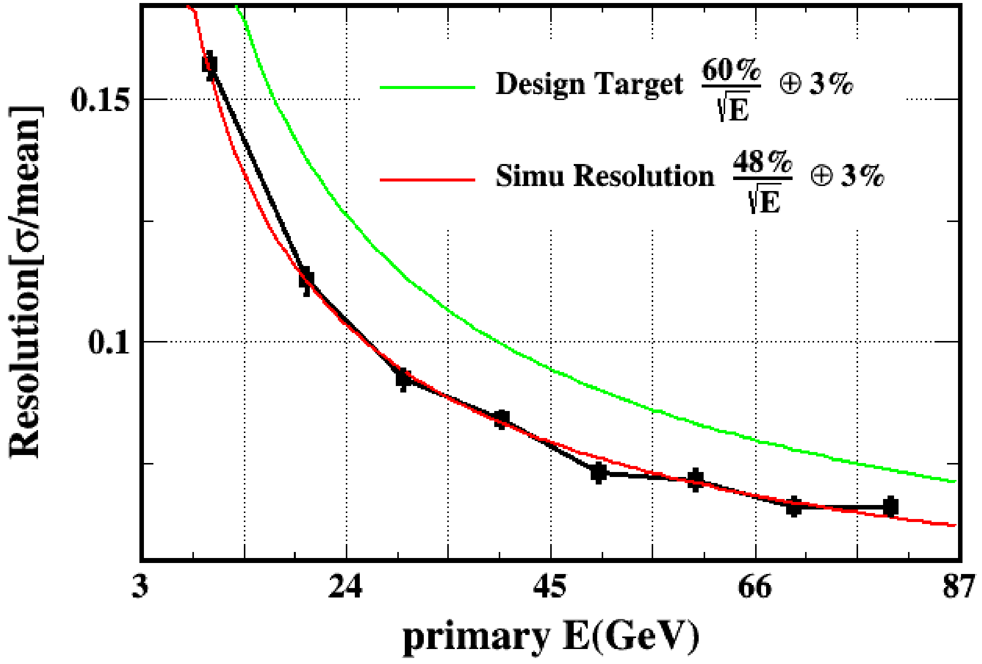
JINST 16 (2021) P03001

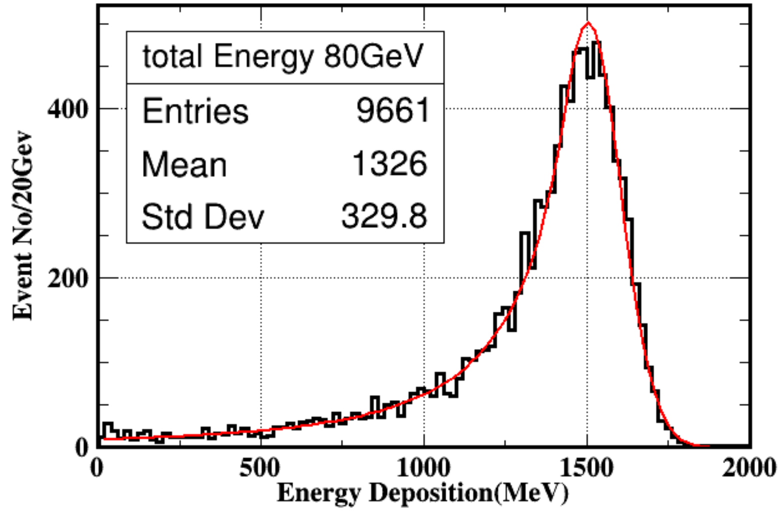
➔ **Design Parameters of the AHCAL Prototype**

- **40 layers, each layer $72 \times 72\ \mathrm{cm}^2$**
- **Steel absorber: $20\ mm$**
- **Scintillator size: $40 \times 40 \times 3\ mm^3$**

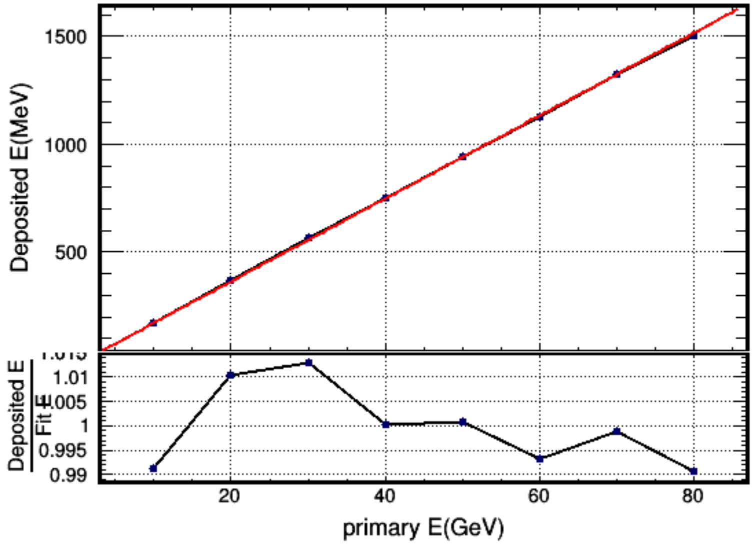
➔ **K_{L} Performance of the AHCAL Prototype**

- **Energy Linearity: $\pm 1\%$**
- **Energy Resolution: $\frac{48\%}{\sqrt{E(GeV)}} \oplus 3\ \%$**





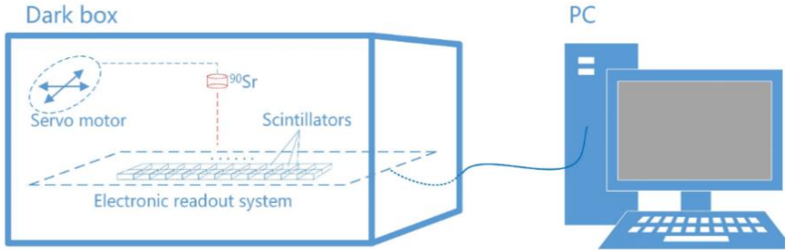
Energy deposition of 80 GeV K_{L}

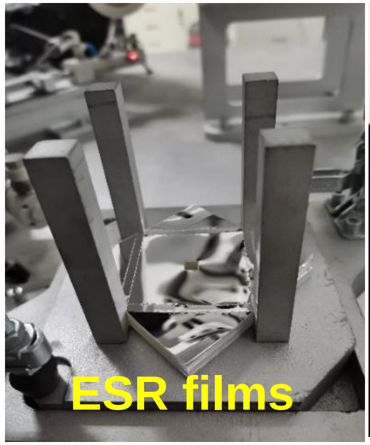


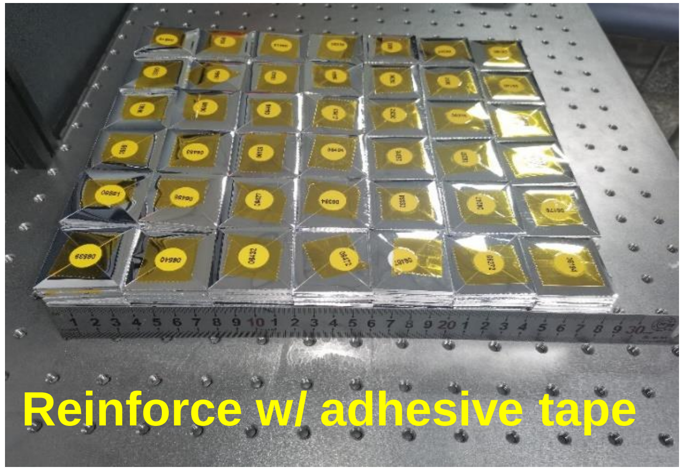
Energy linearity ($\pm 1\%$)

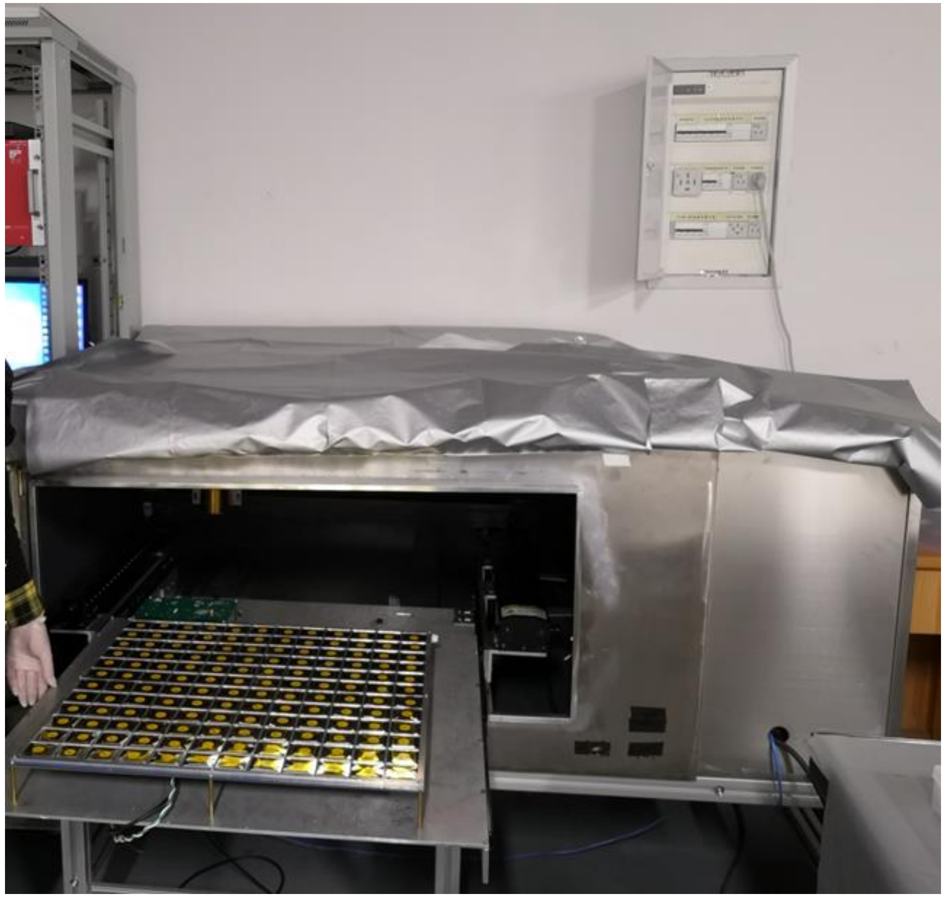
Scintillators

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







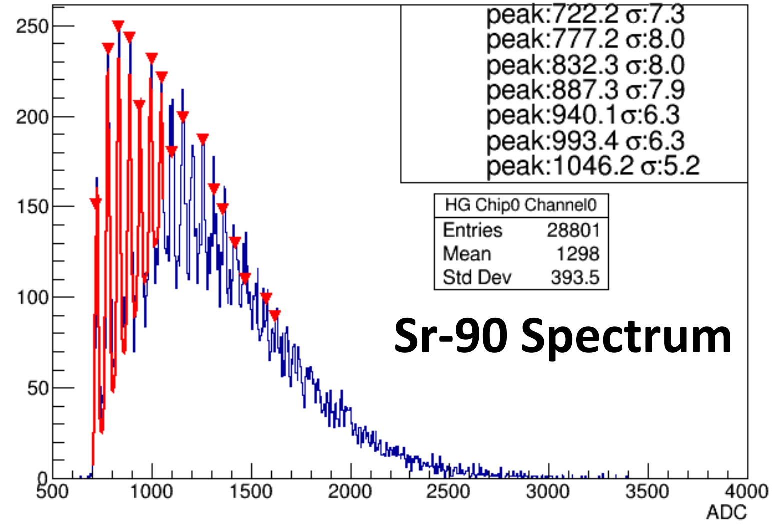


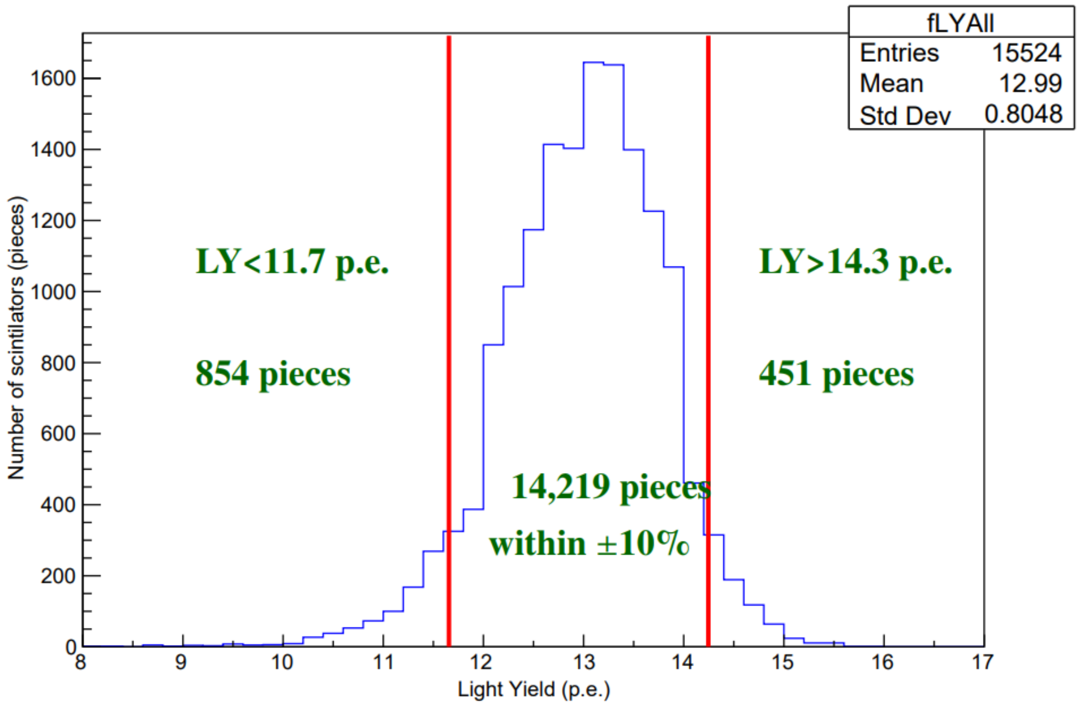
Scintillators

JINST 17 (2022) P05006

- ❖**The batch test system**
  - ○ **HPK 13360-1325PE SiPM + SPIROC readout**
  - ○ **144 channels / batch**
  - ○ **The light yield is fitted by landau-gauss function**

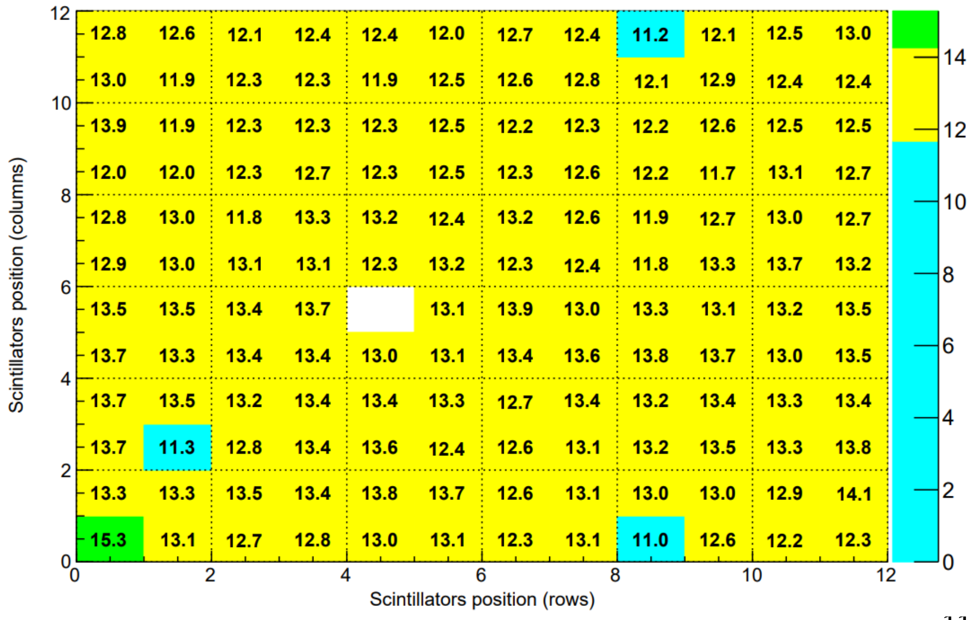
➔**14219 out of 15524 scintillators are within 10% of Light Yield window, selected for construction.**





Light yield for all scintillators

Light yield for one batch of scintillators

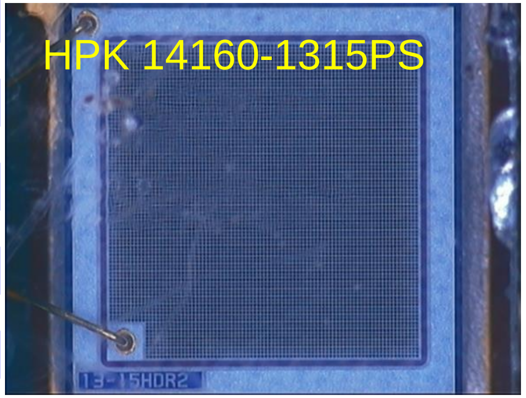


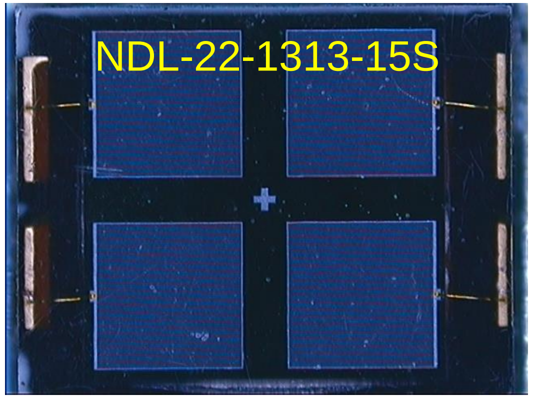
SiPM

NIMA 980 (2020) 164481

❖ **HPK-SiPM**
- Low PDE, dark rate and crosstalk
- High breakdown voltage
- Better quality control
- 38 layers (38 × 324 = 12312)

❖ **NDL-SiPM**
- High PDE, dark rate and crosstalk
- Low breakdown voltage
- Low price
- 5 layers (5 × 324 = 1620)

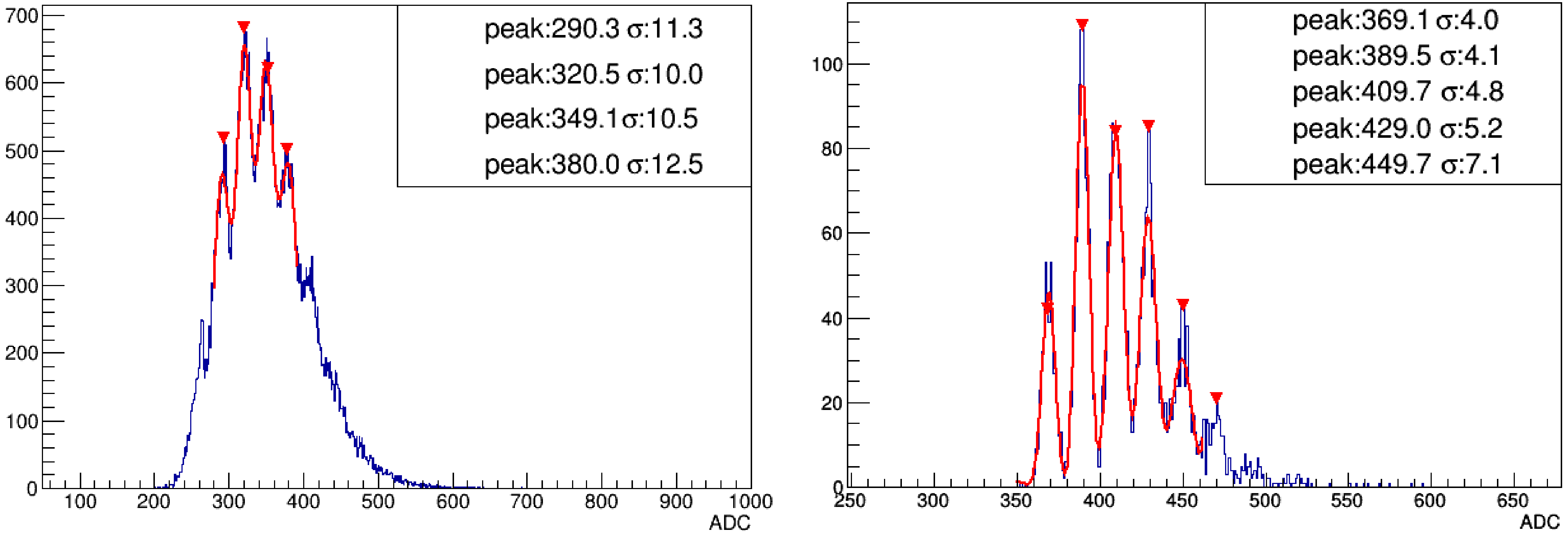




Company	HPK		NDL
Type	13360-1325PE	14160-1315PS	22-1313-15S
Light output [p.e.]	13	17	20
Crosstalk[%]	1.59	1.17	4.4
Dark Counts [kHz]	120	290	550
Breakdown[V]	53	38	27.5

SiPM

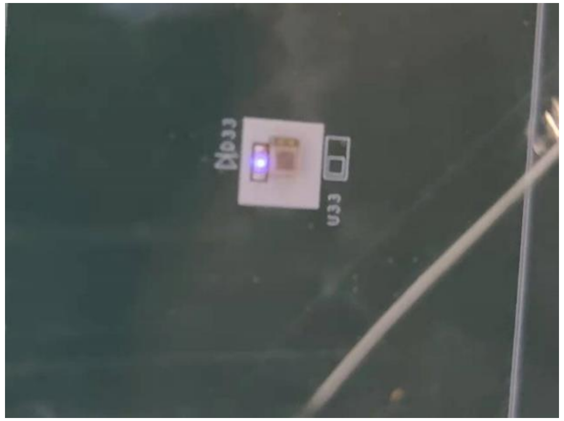
- **LED calibration**
  - Both SiPMs can separate single photon
  - ADC value of a single photon can be calibrated

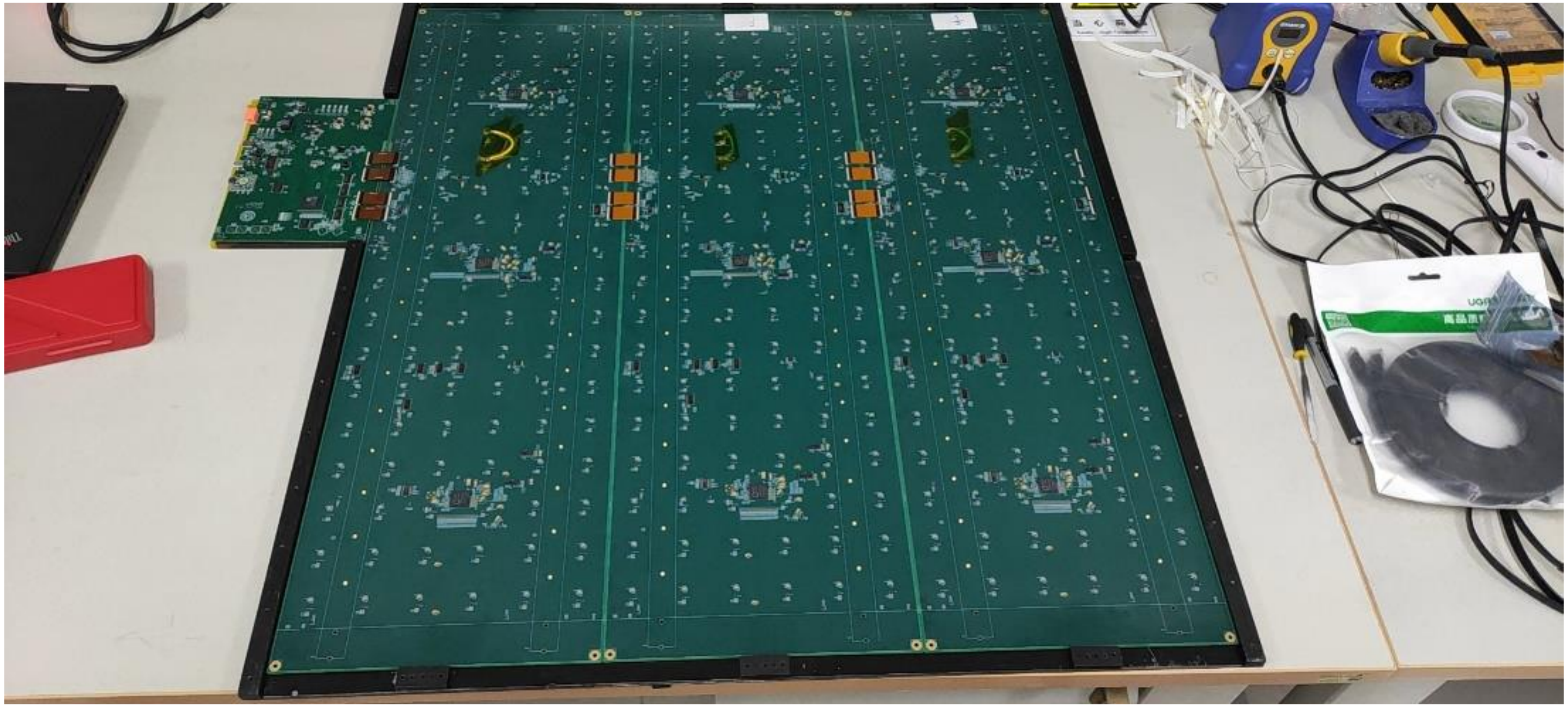


LED spectrum for NDL (left) and HPK (right) SiPMs

Electronics

- Each layer is composed of 3 HBUs and 1 DIF
  - Each layer has 324 SiPMs, hence has 324 channels
  - Each SiPM has a LED side by side for calibration
  - The 324 channels are readout by 9 SPIROC chips
  - There are 48 temperature sensors on each layer



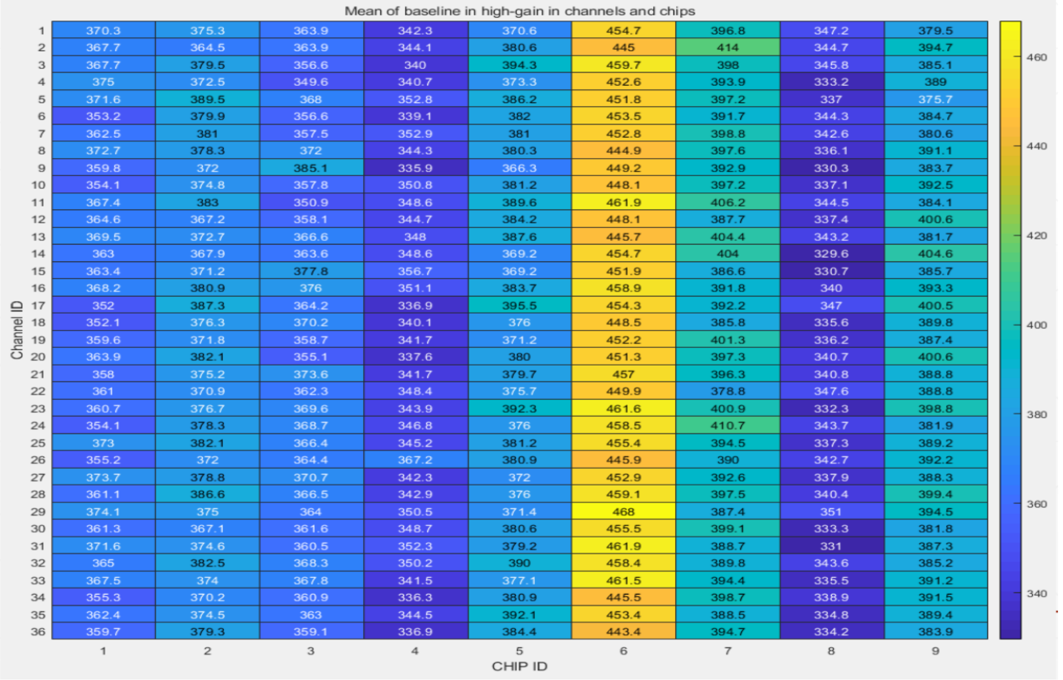


Electronics

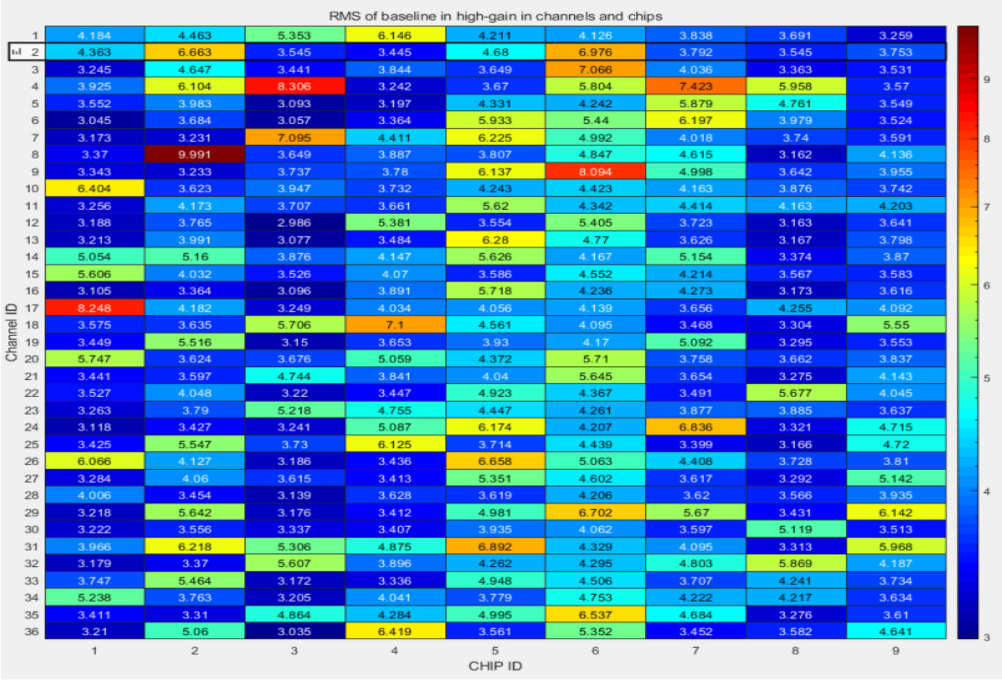
❖ **The HBUs after welding were tested**

- 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

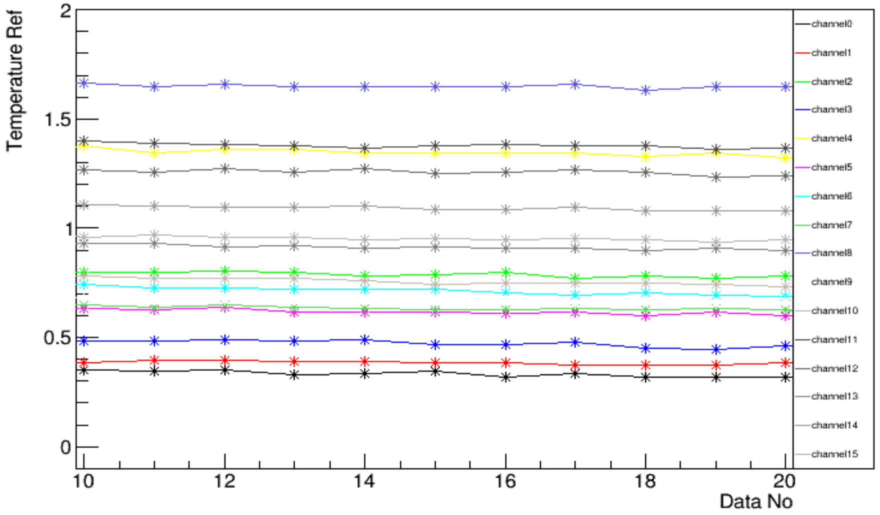


Pedestal width of each channel



Electronics

- The temperature of single-layer HBU is ~ 1 ^{0}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



Reference temperature

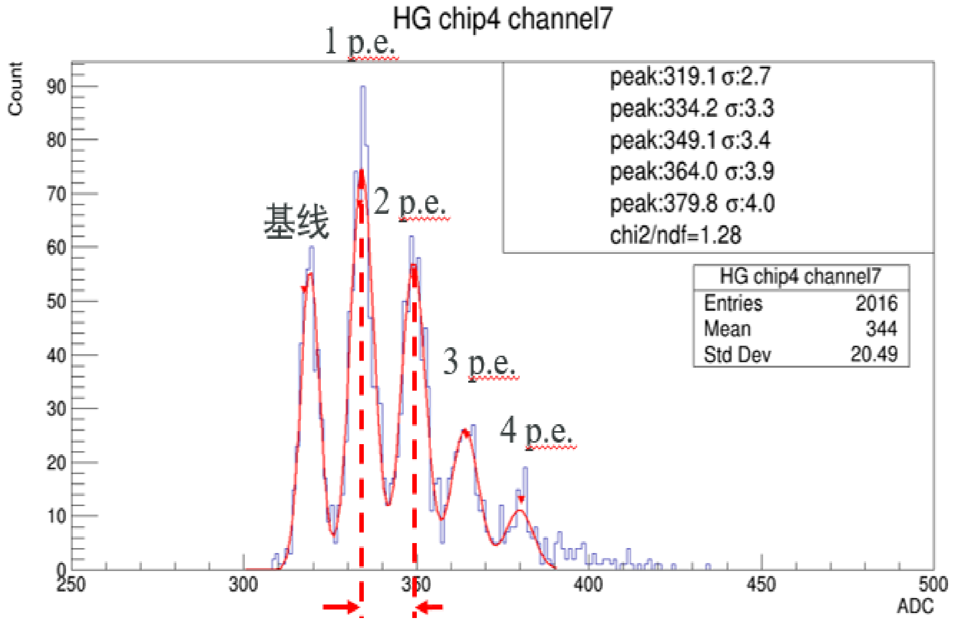
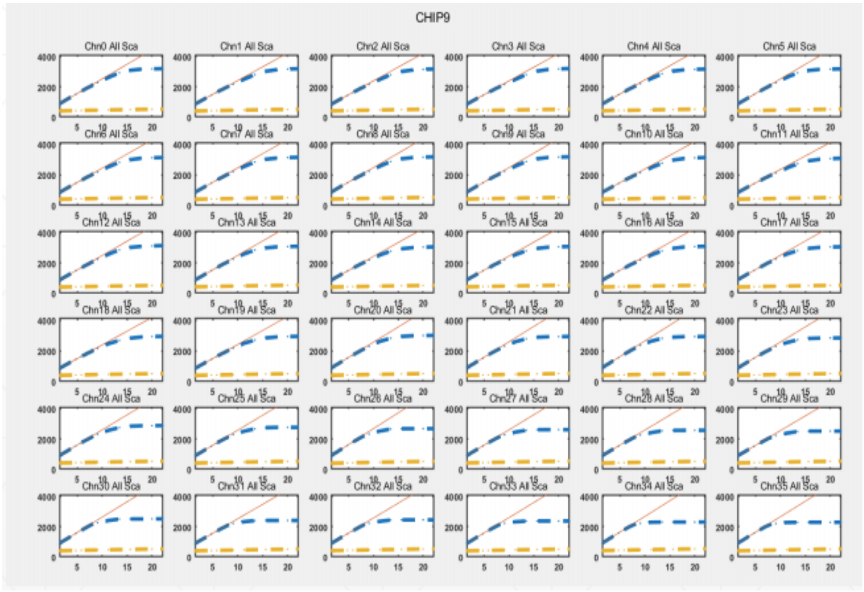


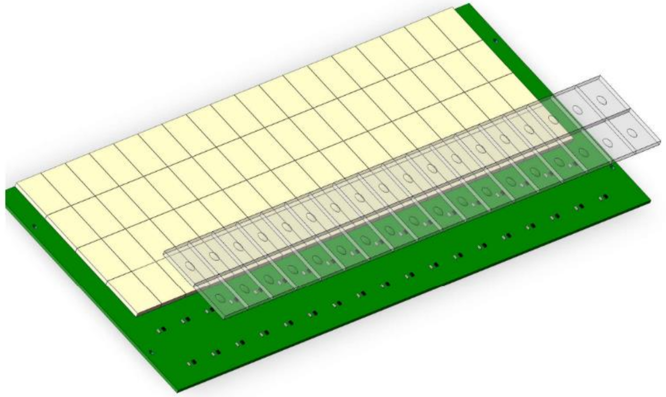
Photo-electron peak



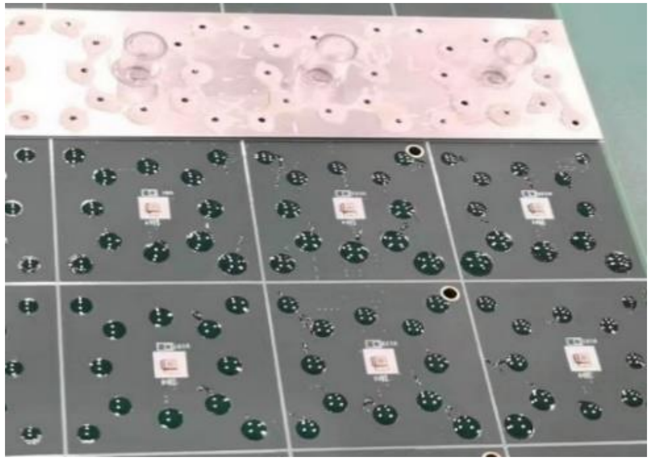
High/Low gain calibration

Assembly of Scintillator, SiPM and HBU

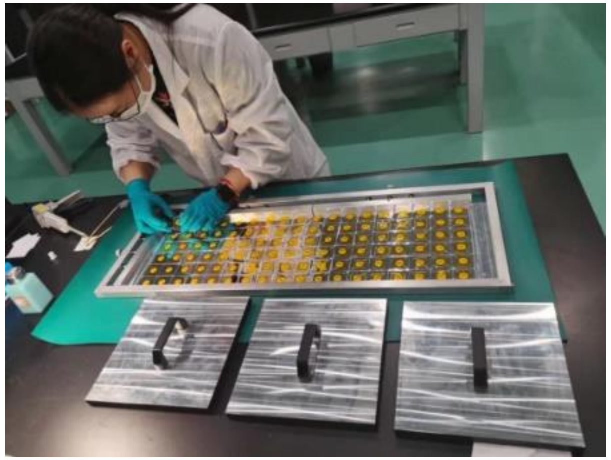
- ❖ Assemble the scintillator on HBU
  - o Fix the scintillators on the HBU with glue
  - o Press them with cover plate for solidification
- ❖ 38 layers with HPK and 5 layers with NDL SiPMs
- ❖ All assembly has completed in early August



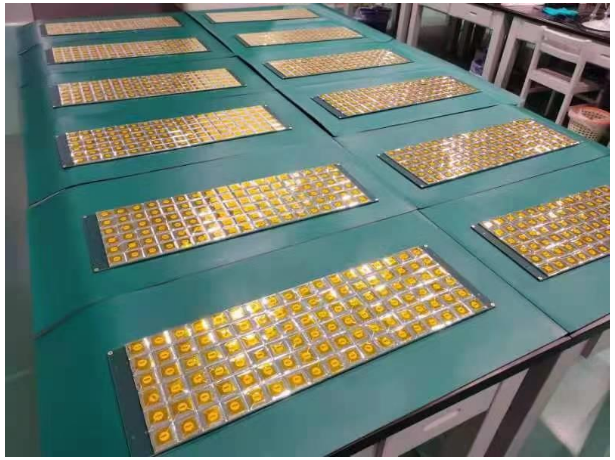
Scintillators on HBU



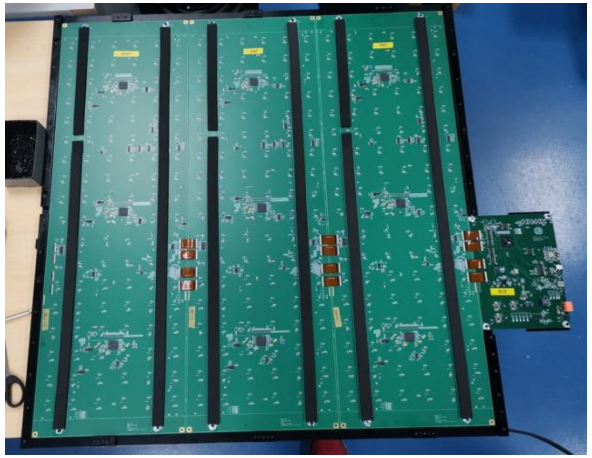
Glue for Scintillators



Scintillators on HBU



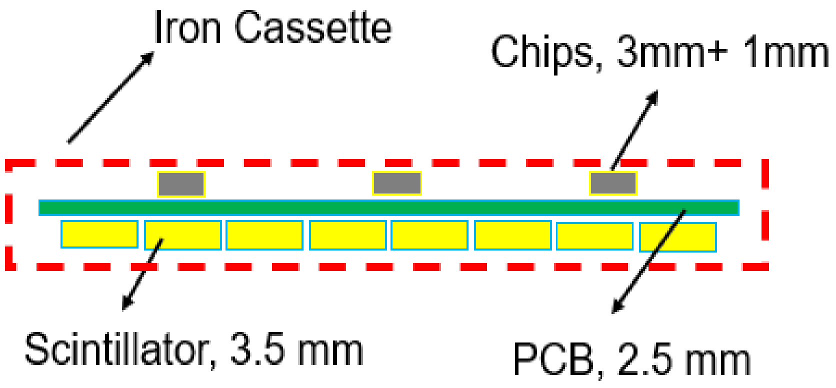
HBU finished



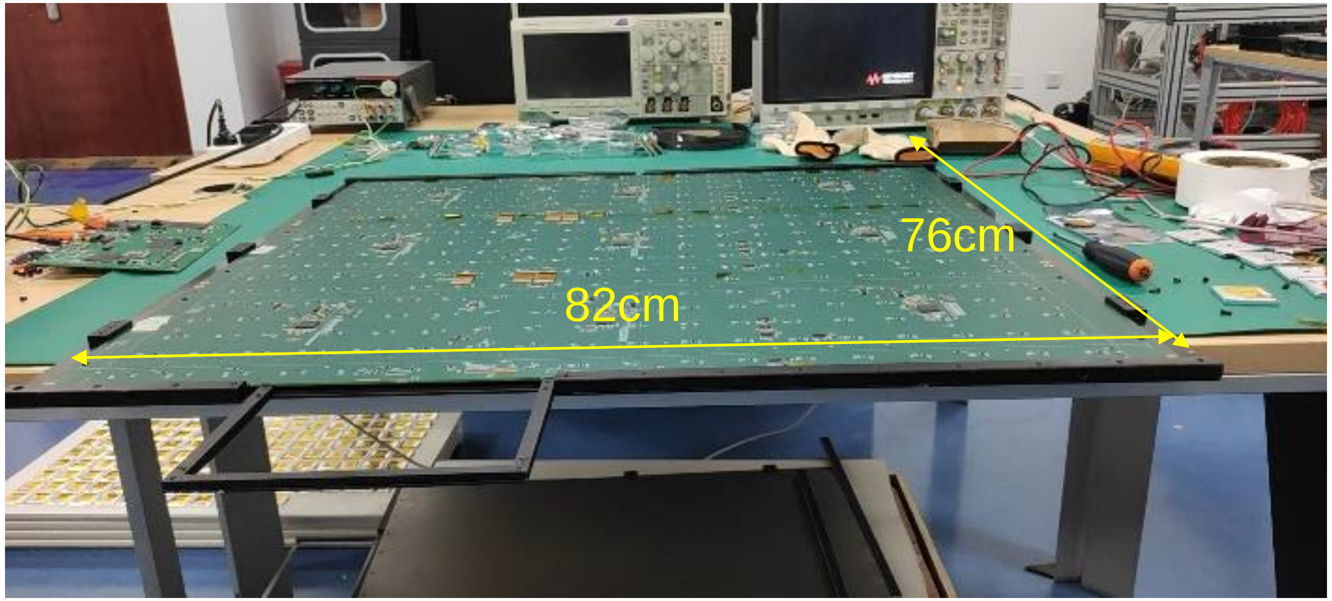
3 HBUs in 1 cassette

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**



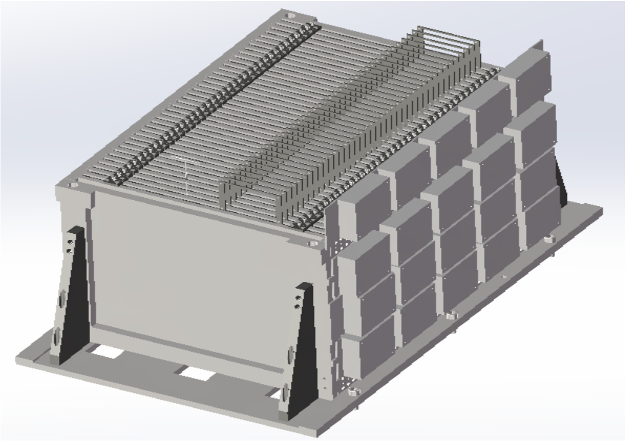
HBU Cassette

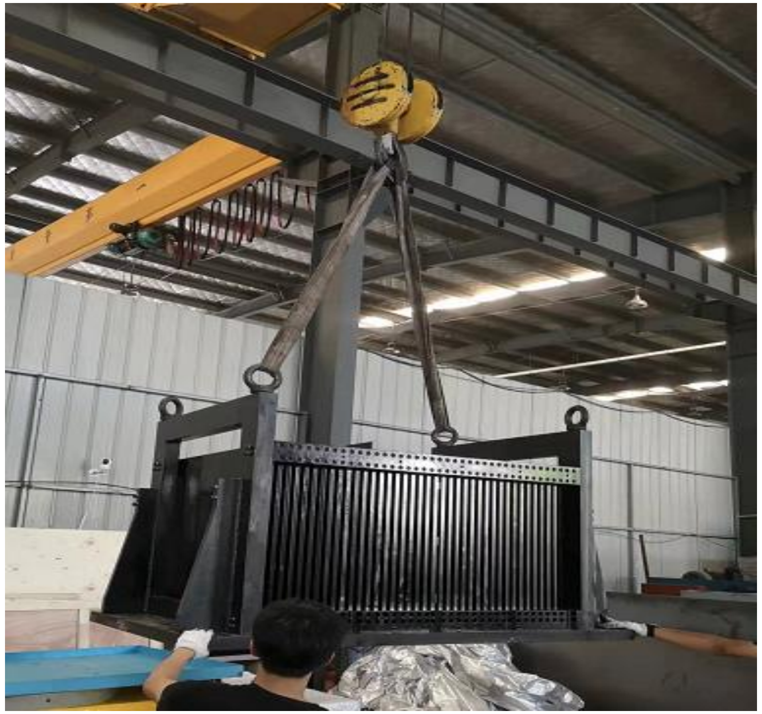


Assembly of AHCAL Prototype

❖ **The assembly of the AHCAL prototype**

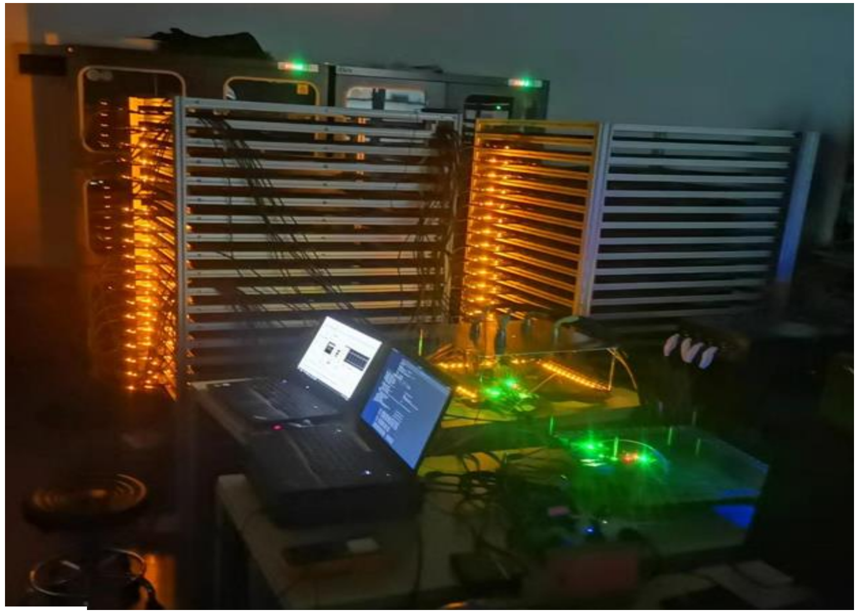
- ○ **Prototype structure based on cassettes (14mm)**
- ○ **HBU cassette can be easily inserted into the gap between neighbor absorbers (14.5mm)**

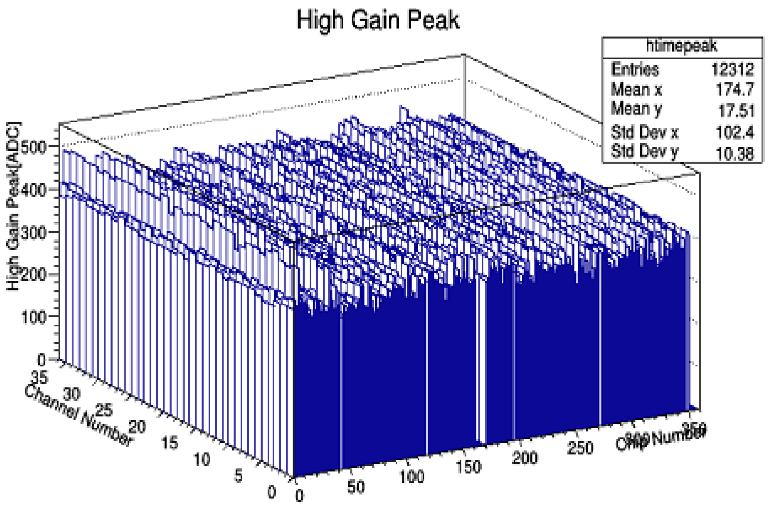




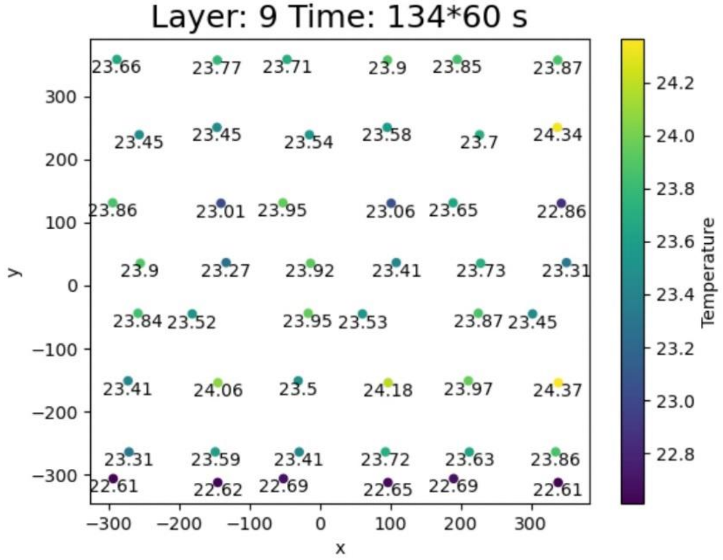
❖Cosmic Ray Test

- 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 ^{o}C higher than room temperature.

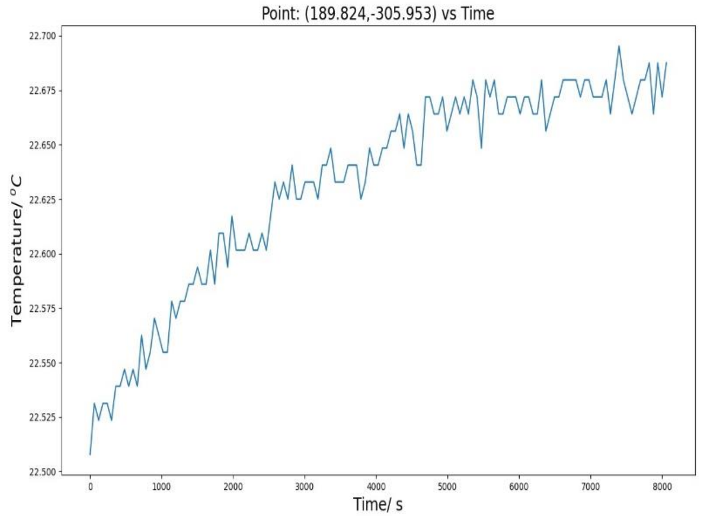




pedestal



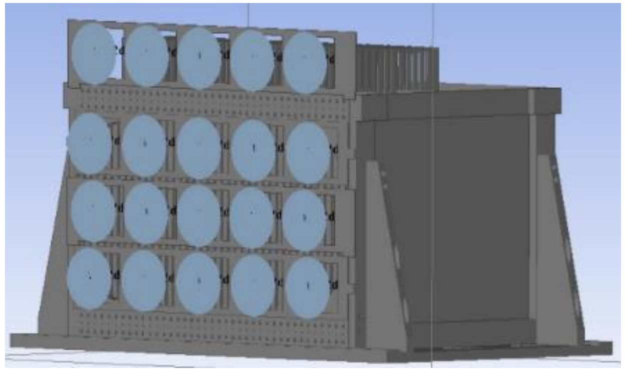
Temperature in one layer

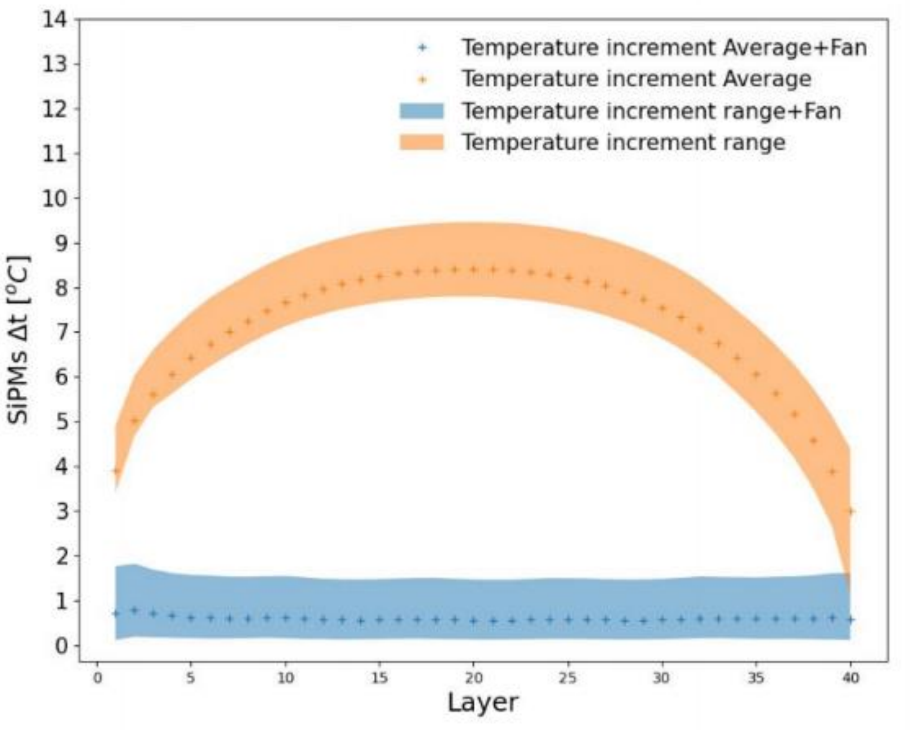


Temperature vs Time

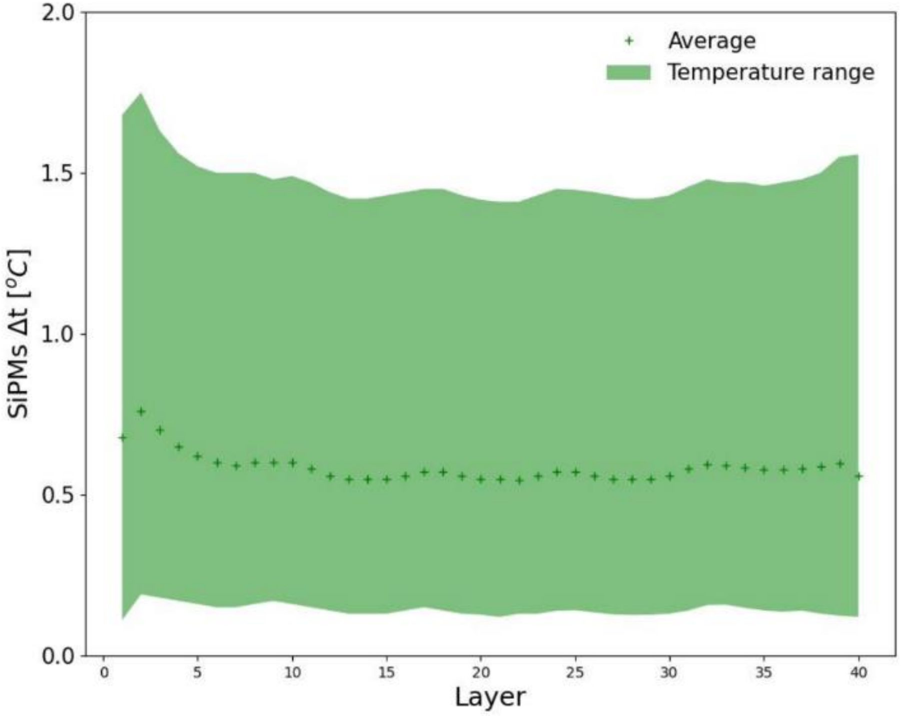
Temperature Simulation for AHCAL

- 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, $\Delta T < \sim 2^0C$





SiPM Temp. vs No. of layer

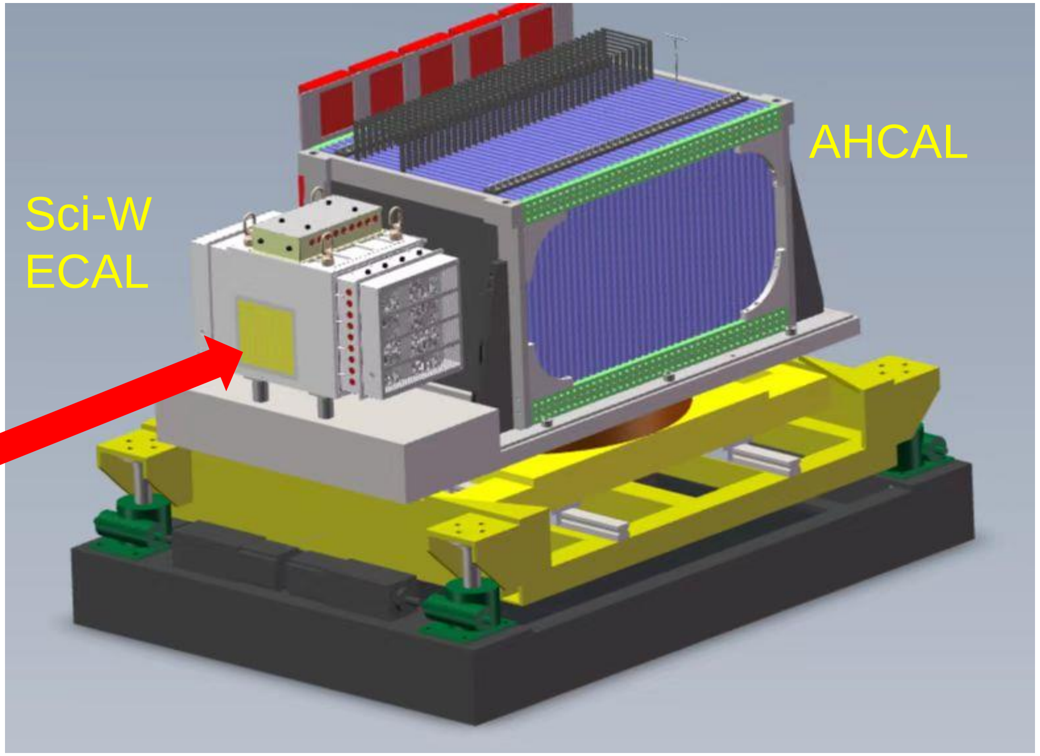


SiPM Temp with fan vs No. of layer

Preparation for Test Beam

❖ The adjustable platform is designed for Test Beam at CERN

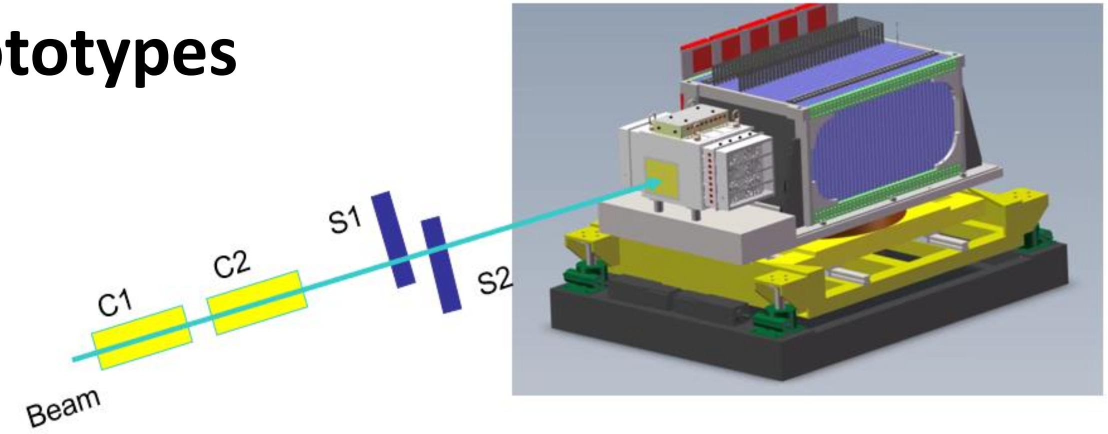
- The platform can support AHCAL and Sci-W ECAL prototypes at the same time
- Horizontal movement is ±20 cm, vertical movement (up/down) is ±15 cm

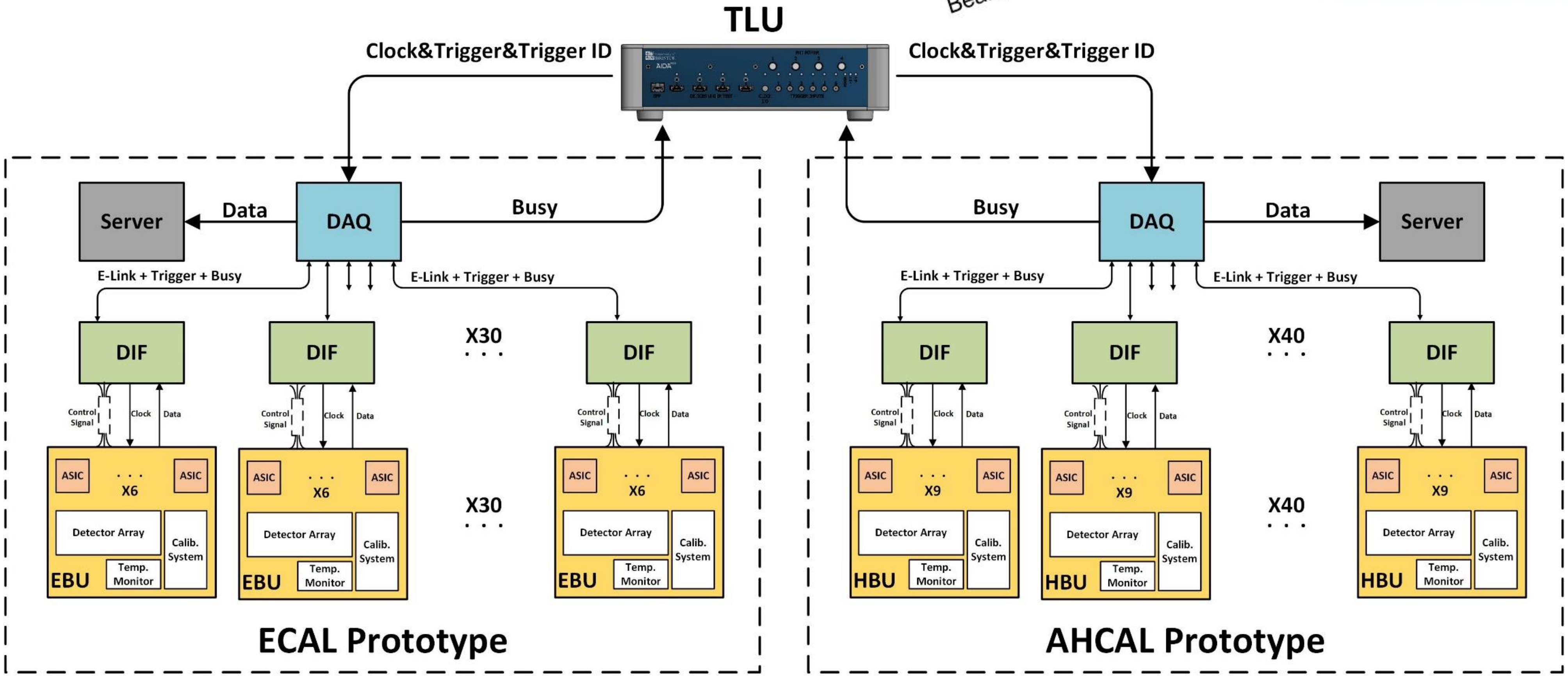


Trigger Logic Unit (TLU)

❖ **DAQ system for ECAL and AHCAL Prototypes**

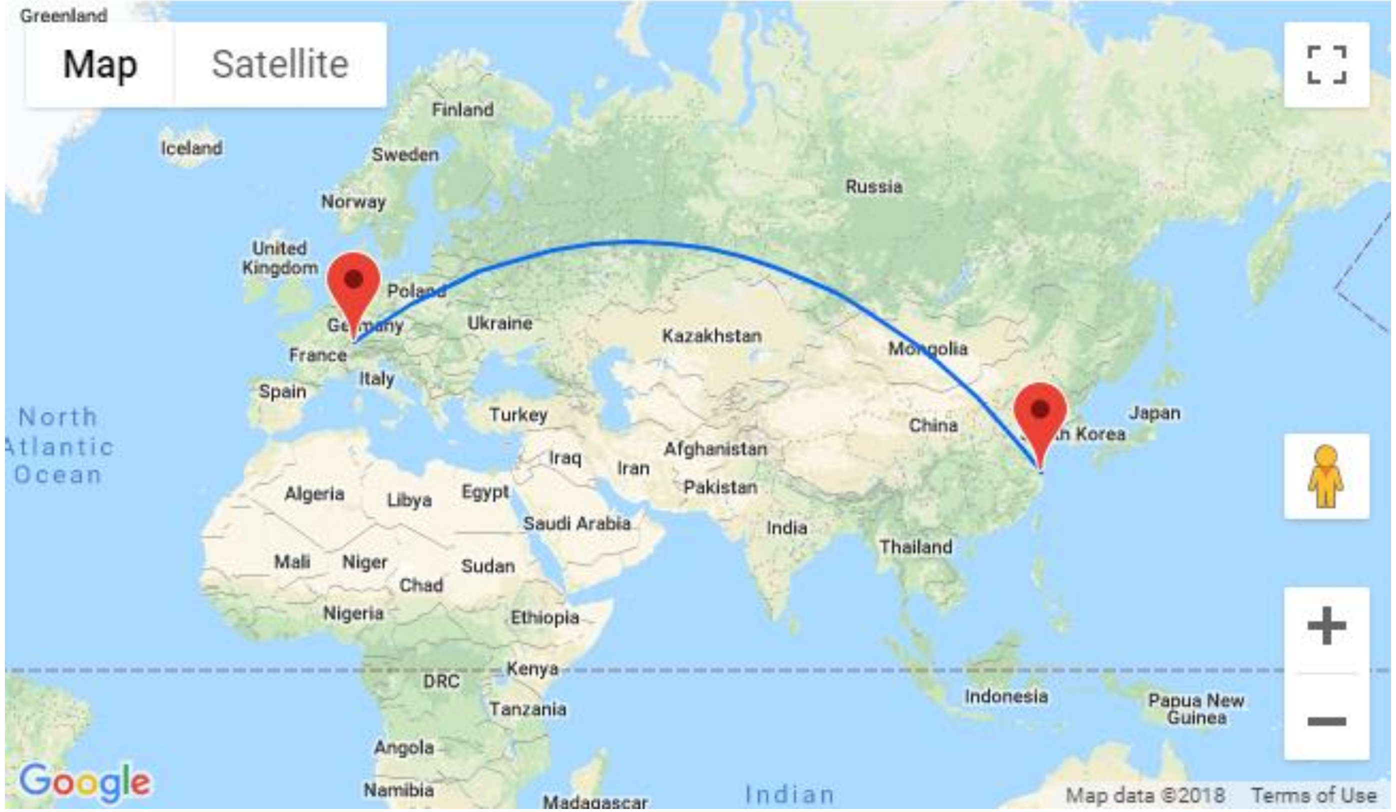
- ECAL has 30 DIFs, AHCAL has 40 DIFs
- Using TLU to synchronize two systems





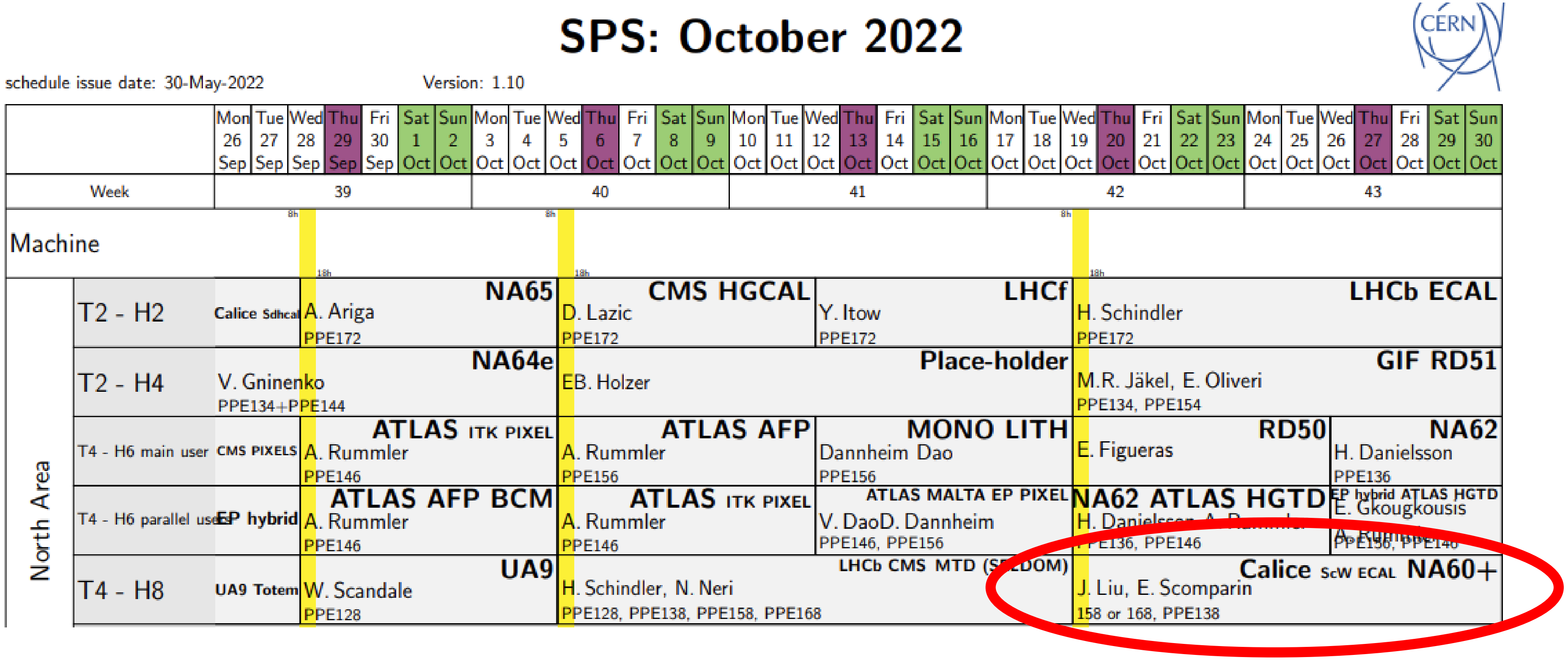
Preparation for Test Beam

❖ 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.**
  - **Electron beam: with purity (10 – 99 %), max. Δp/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 !!!