国家重点研发计划
“高能环形正负电子对撞机关键技术研发和验证”

课题三：成像型强子量能器技术验证

量能器技术研究亮点

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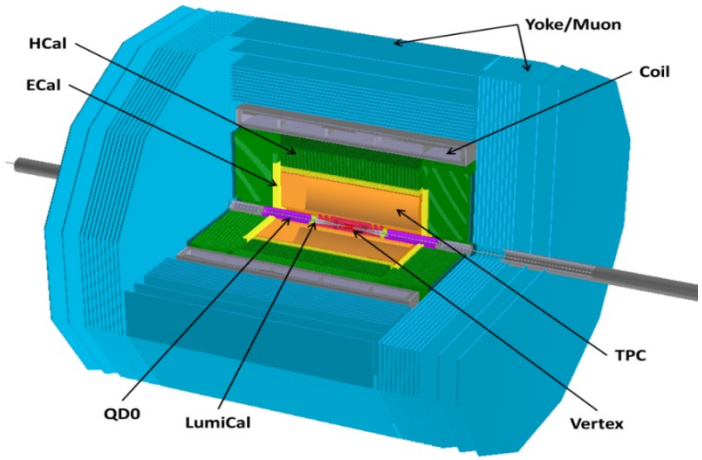
2023.6.19 – 20
高能所

Requirements of CEPC Calorimeter



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

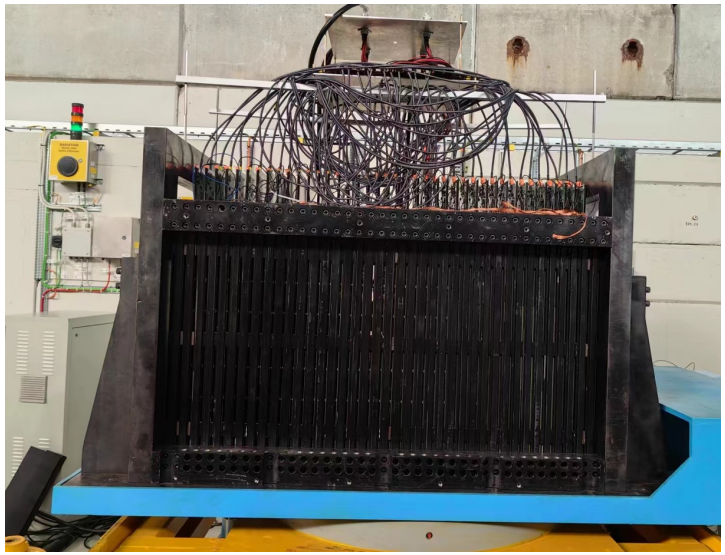
Challenges:

- **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:** $\frac{\sigma_E}{E} \approx 3-4\%$

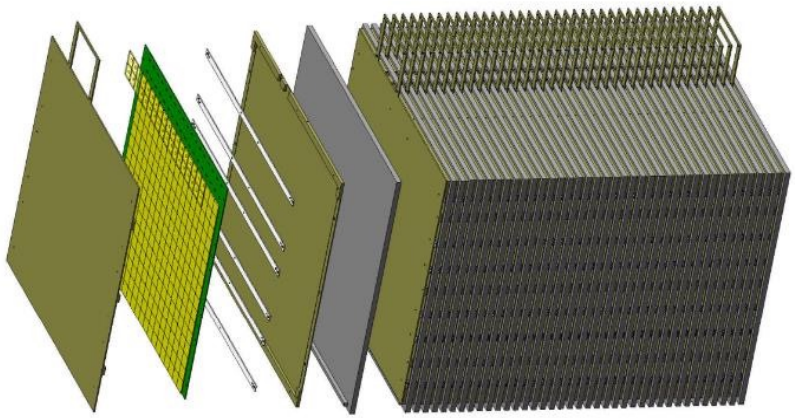
- The Particle Flow Algorithm (PFA) calorimeter concept was proposed
  - High granularity
  - Good track finding
  - "Good" energy resolution

AHCAL Prototype

- Sampling Calorimeter
  - 40 layers, ~ 5 N.I.L
  - 72 cm×72 cm
- Absorber
  - Iron，2 cm thickness
- Sensitive Detector
  - Scintillator+SiPM
  - Cell size：40 mm×40 mm×3mm
  - SiPM：HPK and NDL
- Electronics
  - SPIROC2E ASIC Chip



AHCAL prototype



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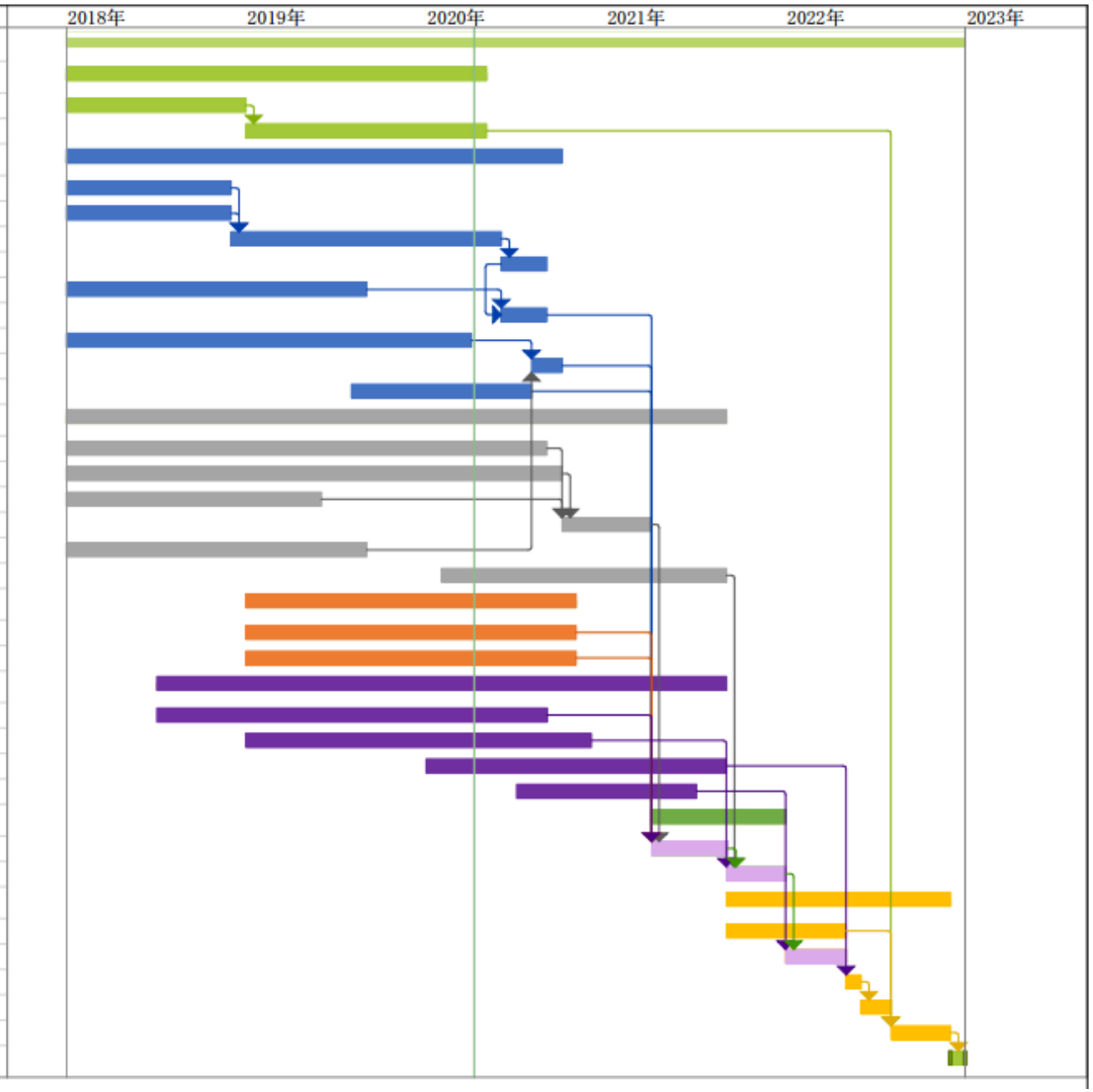

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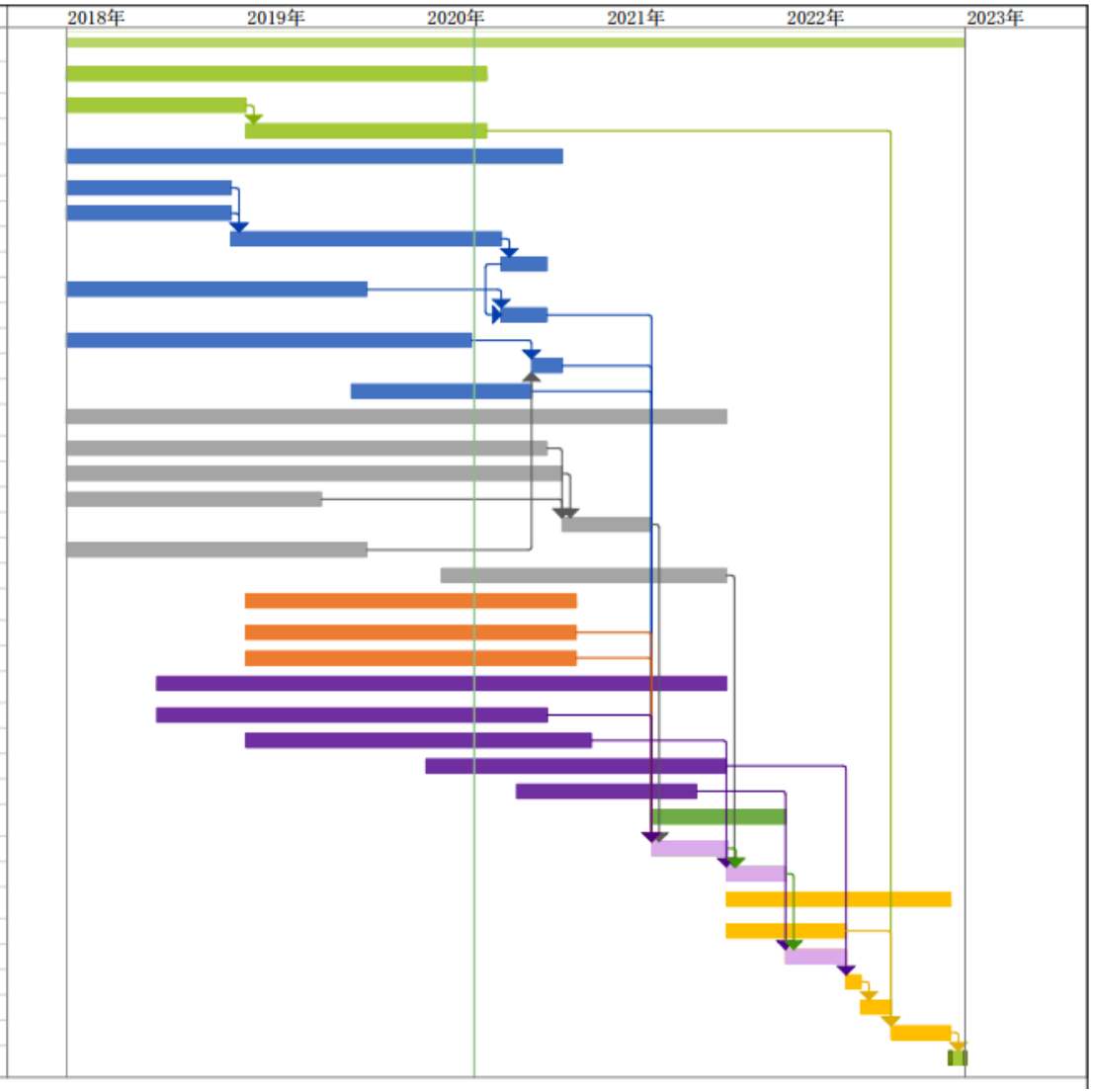
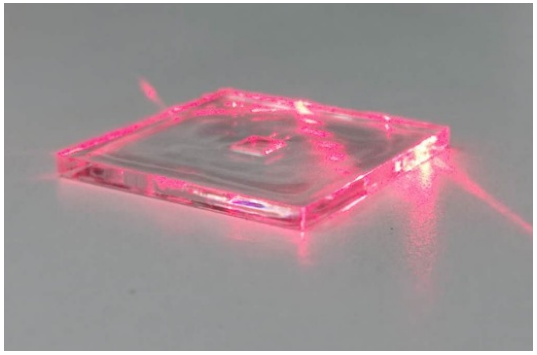
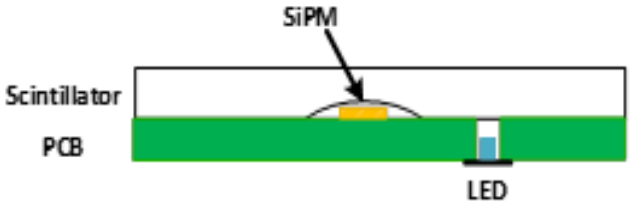
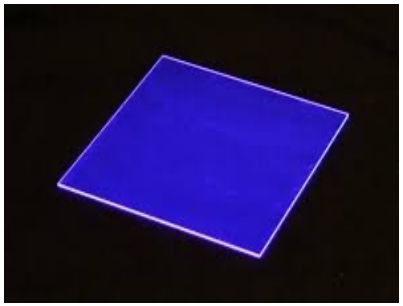


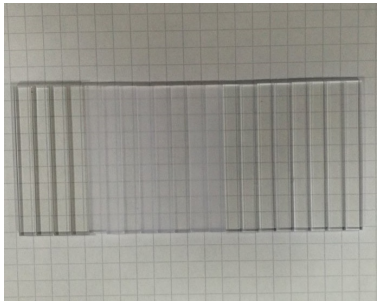
AHCAL scintillator cell

- AHCAL selects plastic scintillator as sensitive cell, and SiPM was used as photon device
- There is a small groove in the middle of the scintillator unit for coupling with SiPM
- In the previous MOST program, ScECAL plastic scintillator strips were cut from a large area scintillator plate, and then mechanically slot it.
- This method is very complex and difficult to control, AHCAL uses injection molding technology



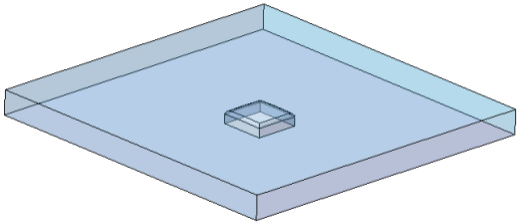




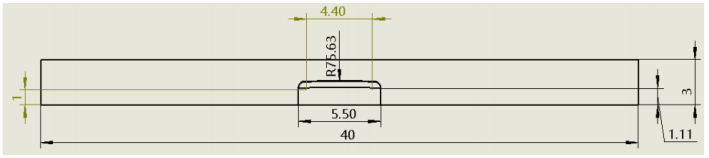


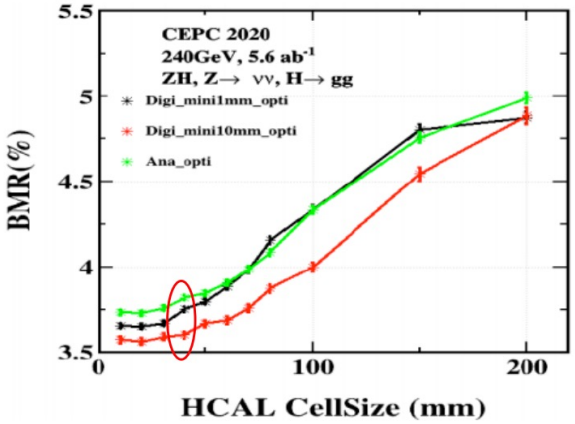
AHCAL scintillator cell

- For increasing the AHCAL prototype size from original 50cm×50cm×35 layers to 72cm×72cm×40 layers;
- Detector cell size was increased from 30mm×30mm×3mm to 40mm×40mm×3mm ;
- The light yield uniformity of detector cell was simulated by G4 and checked by test;
- The results show it is fit the ACHAL requirement.

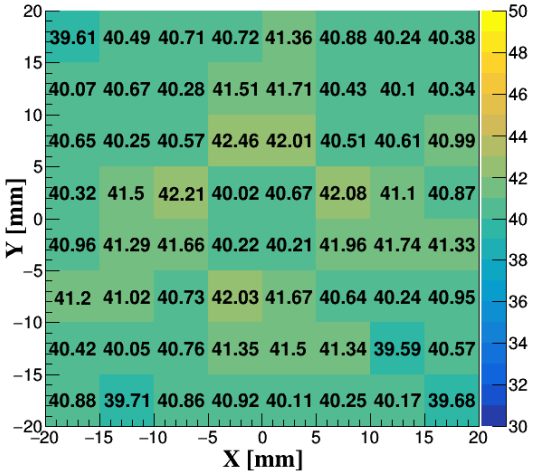


Detector cell

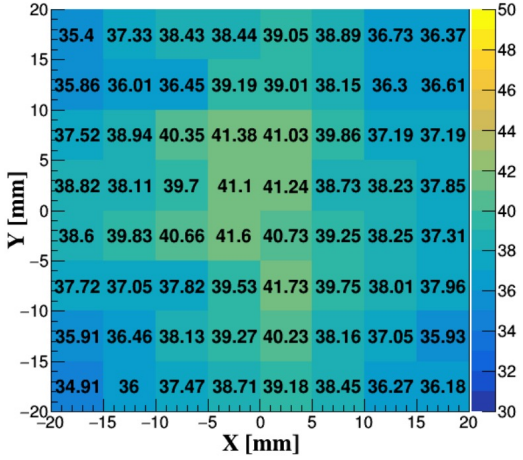




Cell size VS BMR



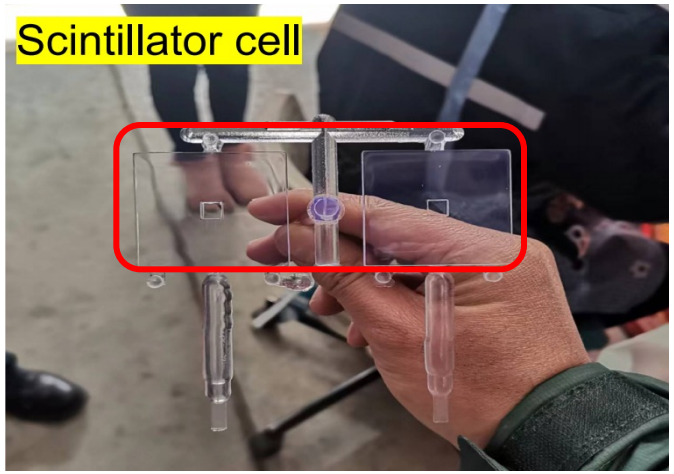
Uniformity simulation result



Uniformity test result

Injection Molding

- For mass production of future 10 M detector cells, injection molding plastic scintillator is good choice;
- Injection molding technology is fast, cheap and good uniformity;
- Formulation of plastic scintillators was optimized, temperature and humidity during production are optimized;
- Under the right conditions, an injection molding machine can produce 600 plastic scintillators per day.

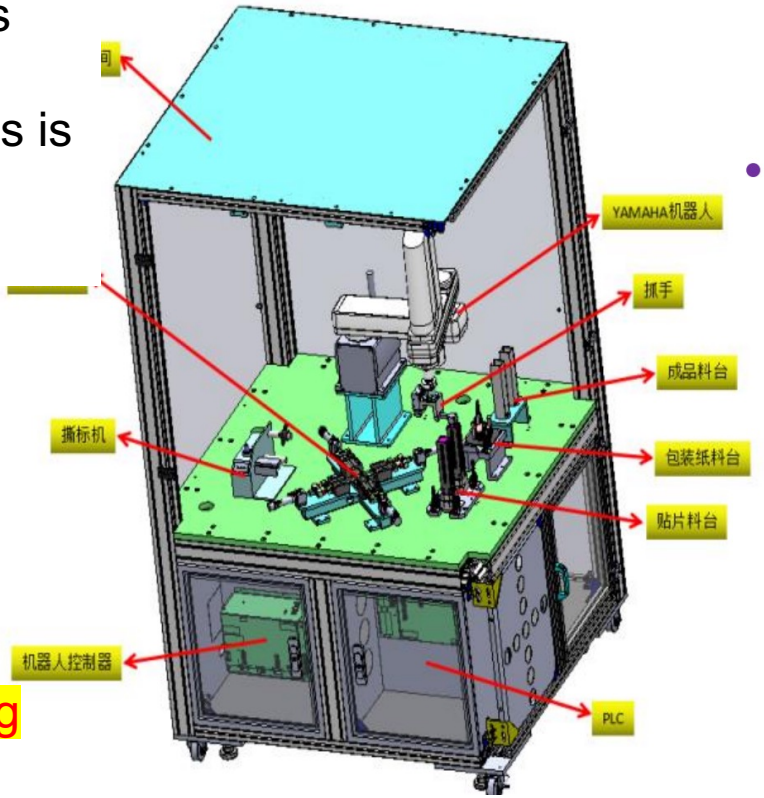


Two pieces of plastic scintillator are produced per injection molding

Scintillator automatic packaging

- For detector packaging, it is too much for manpower doing this work for future CEPC
- Robot packaging detector cells is good uniformity, fast and cheaper.

Detector cells after packaging



- **Robotic arm design is a new way;**

For AHCAL prototype15000 detector cells are packaged by this machine.

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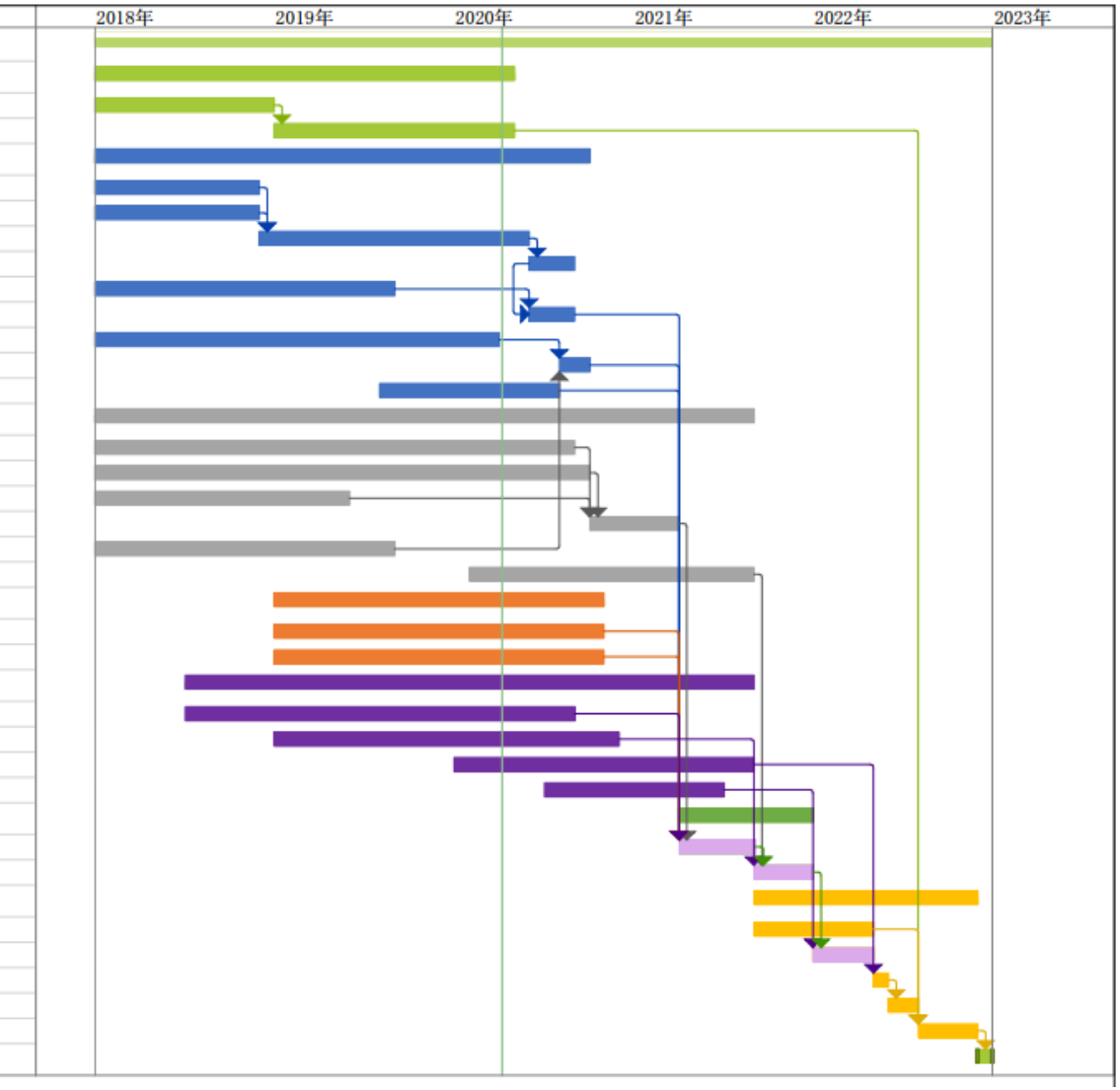
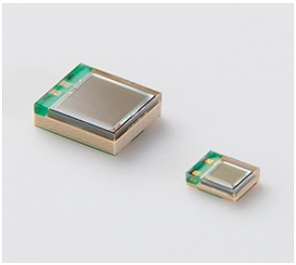
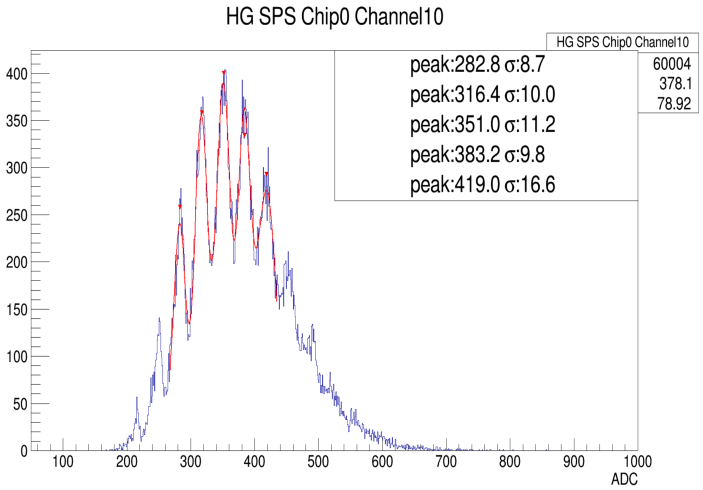


Trail Batch Application of Domestic SiPM

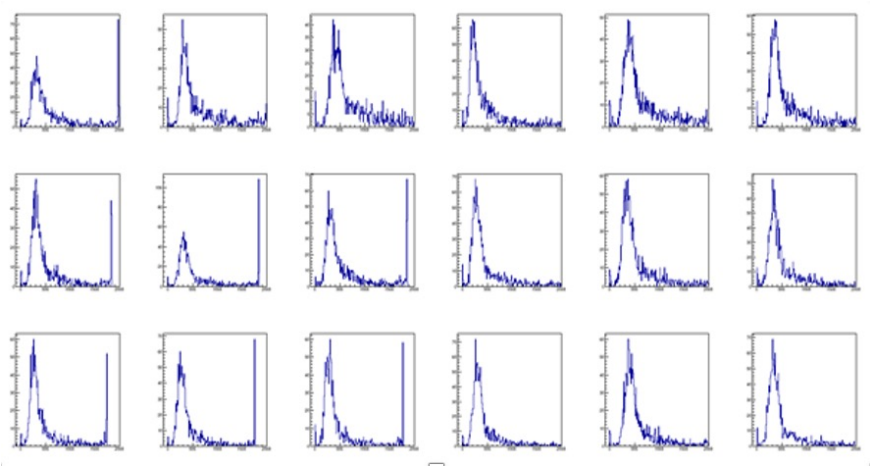
- Two different types SiPM were selected in this prototype
  - HAMAMATSU, 38 layers
  - NDL, two layers (648 channels)



S14160-1315PS NDL



LED Test



MIPs signal in Beam Test

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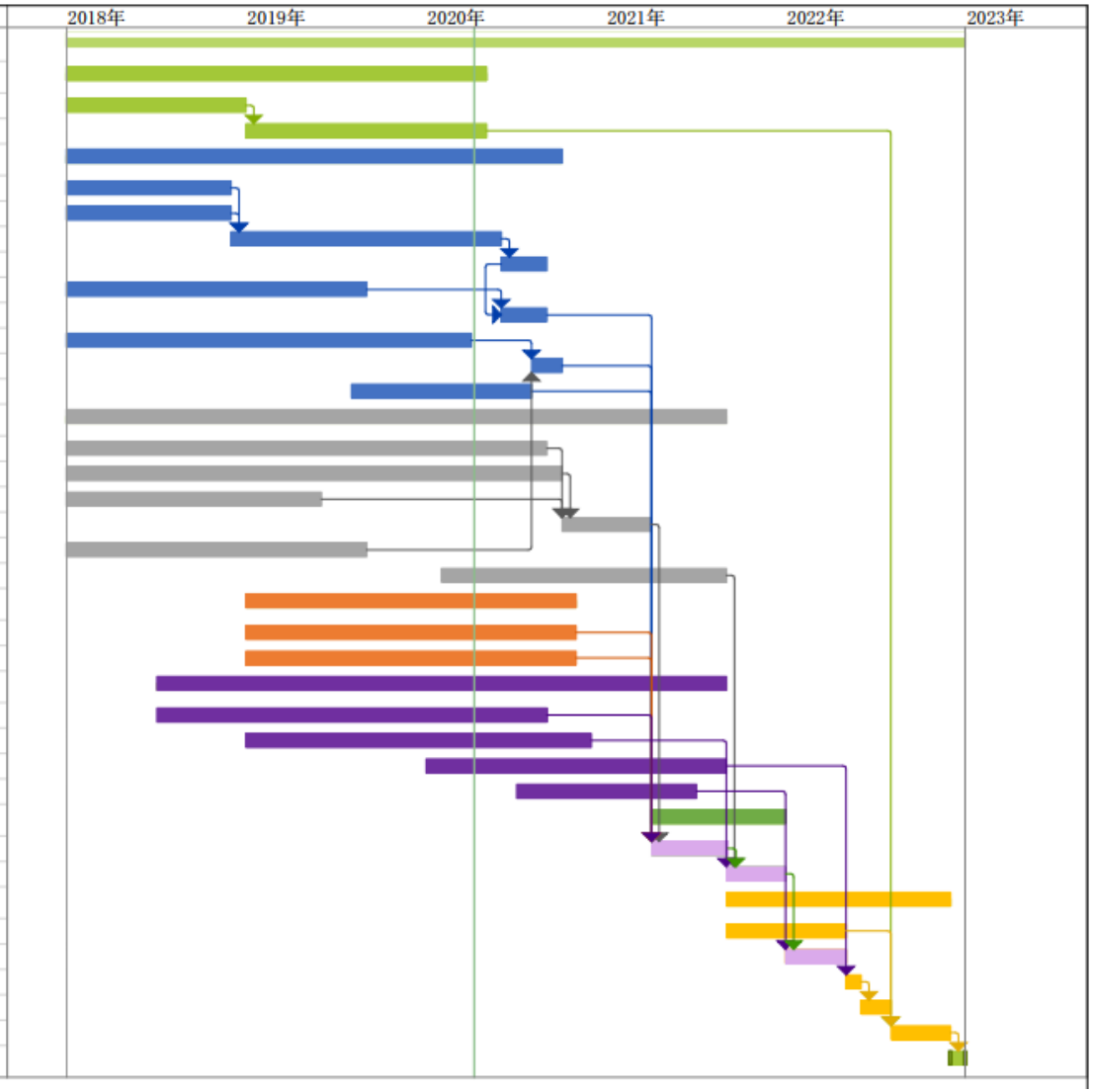
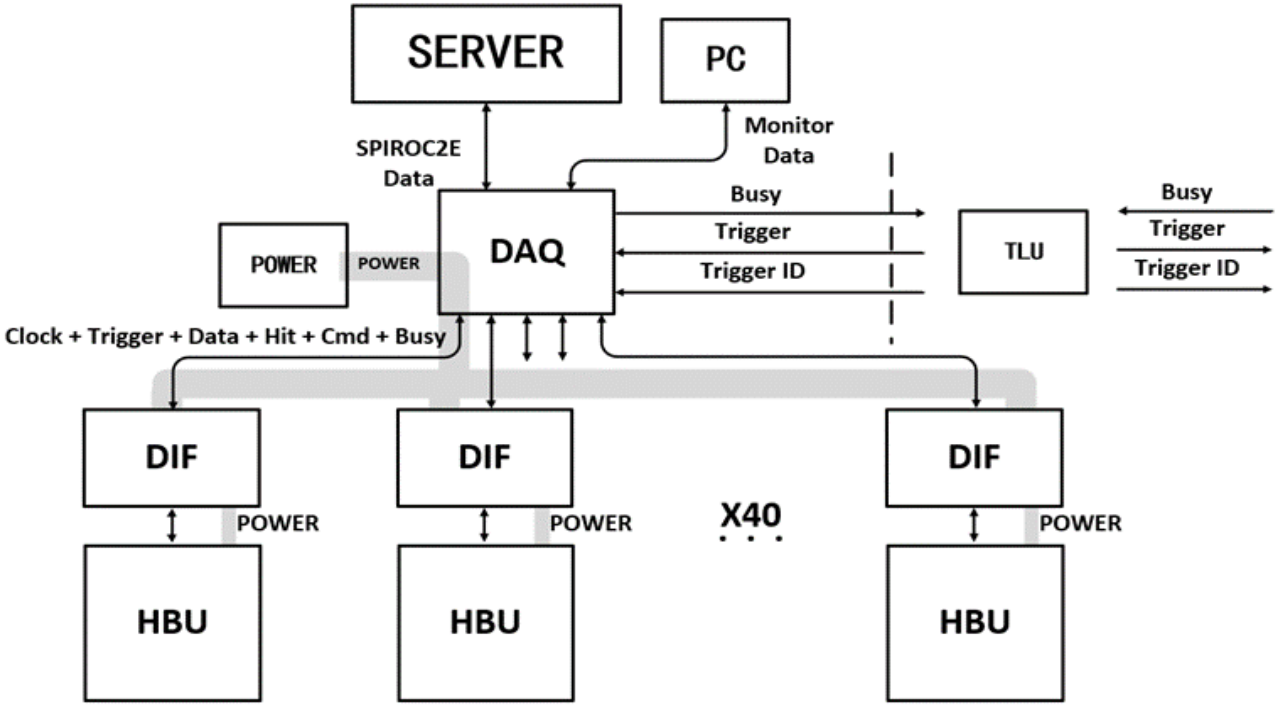


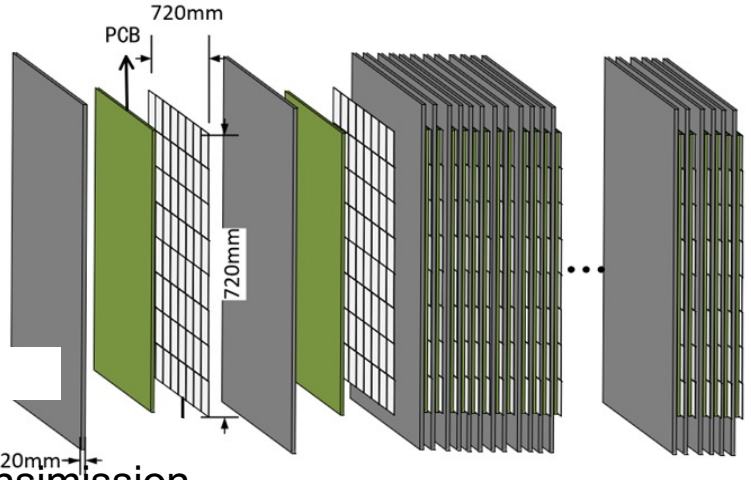
Readout System

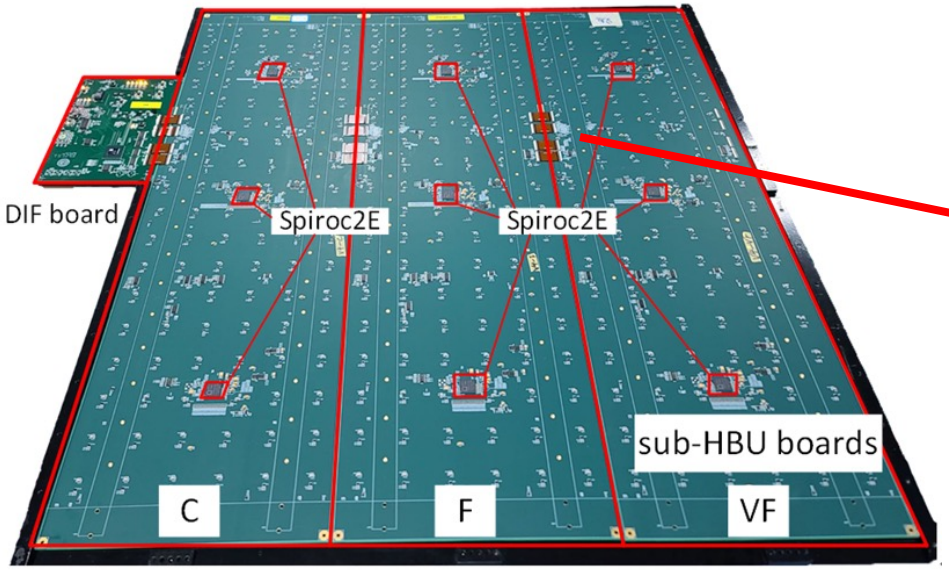
- Data acquisition
  - Independent Data link for Monitor Data
  - Clock, trigger from TLU to sync with other system
- Power supply
  - Power -> DAQ board -> DIF board -> HBU

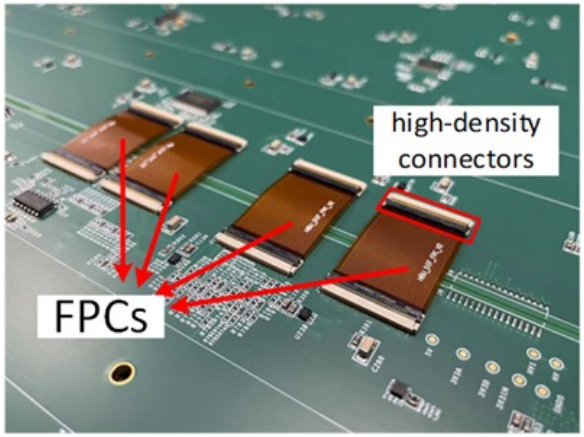


High-integrated Readout

- Embedded readout electronics
  - To realized the “sandwich” AHCAL, embedded readout electronics is adopted. The top layer of the PCB is the readout circuit and the bottom layer is SiPMs and scintillators.
- Large sensitive area
  - The large sensitive area is divided into 3 PCB board (sub-HBU).
  - High-density connectors are used for signal transimission.

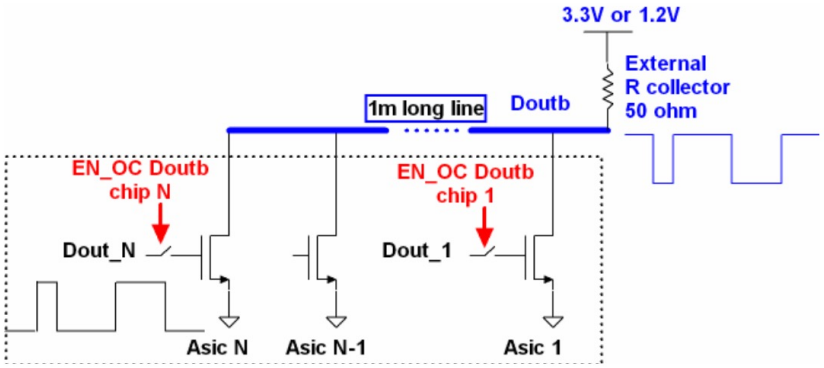




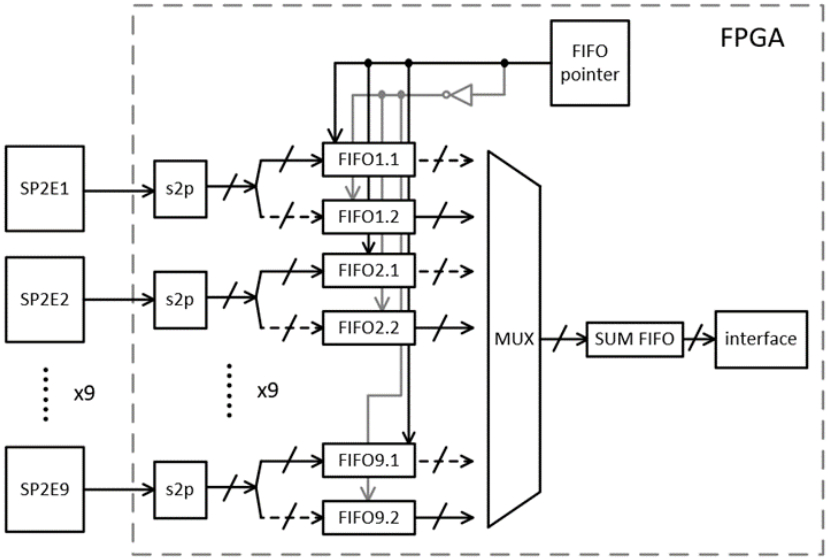


High-rate readout

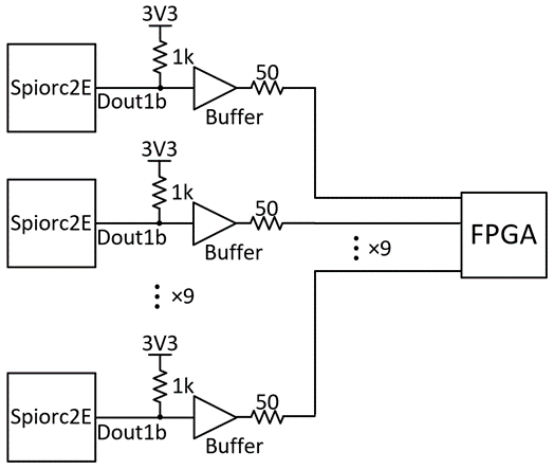
- Serial Readout
  - Default usage
  - Daisy chain
  - <83Hz
- Parallel Readout
  - Ping-pong readout in FPGA
  - >1kHz in beam test



Serial Readout Circuit



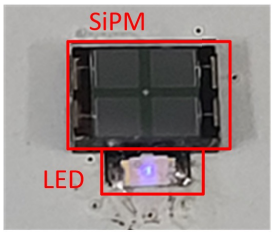
Ping-Pong Readout Logic



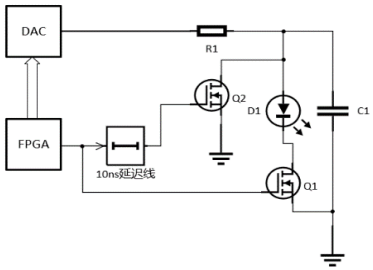
Parallel Readout Circuit

Light Calibration

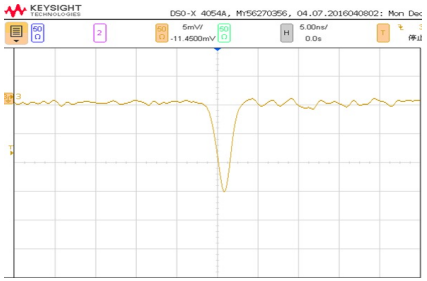
- Motivation
  - Obtain the photon-electron spectrum of each SiPM to calibrate the gain.
- Key point
  - Generate 10ns-wide short light pulse, which is similar to the scintillator light.
    - ✓ A fast driver circuit is developed. The light intensity can be control by the driver voltage and the light width can be control by the delay line, which control the by-pass circuit.



LED & SiPM

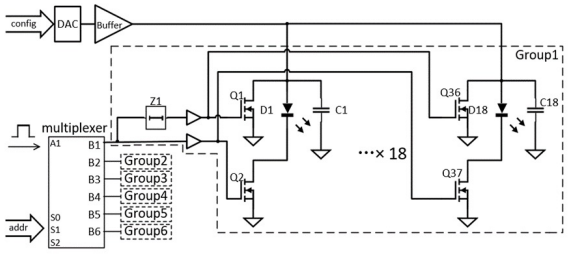


LED driver circuit

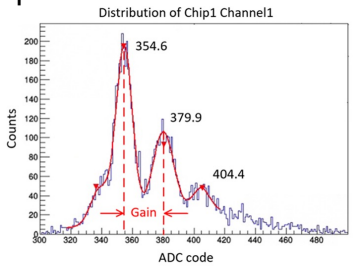


LED waveform

  - Calibrate 12,960 SiPMs in the short time
    - ✓ The calibration LEDs in each layer are grouped by 6. And one group share common control circuit.



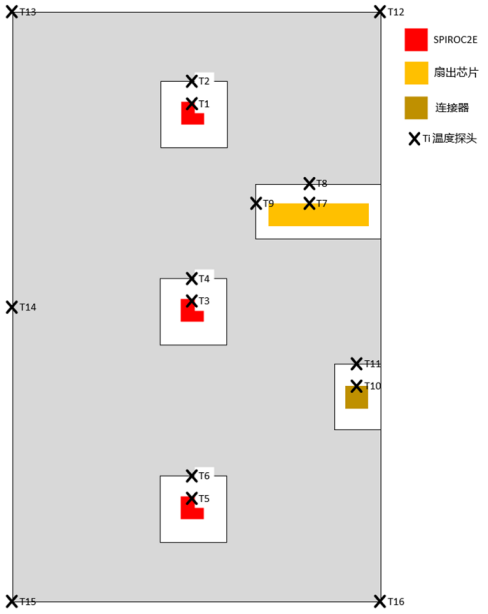
LED Calibration Circuit



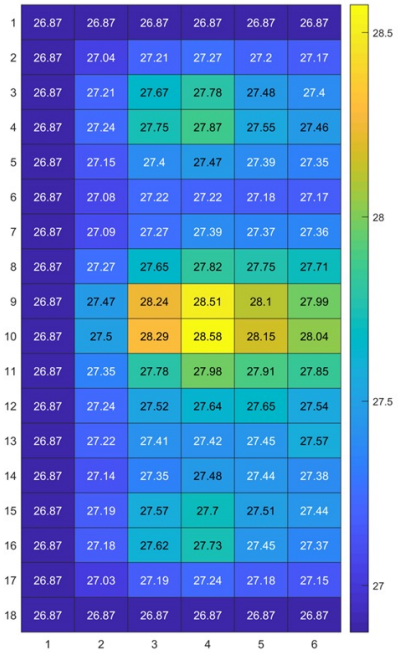
SPS of a SiPM

Temperature monitor

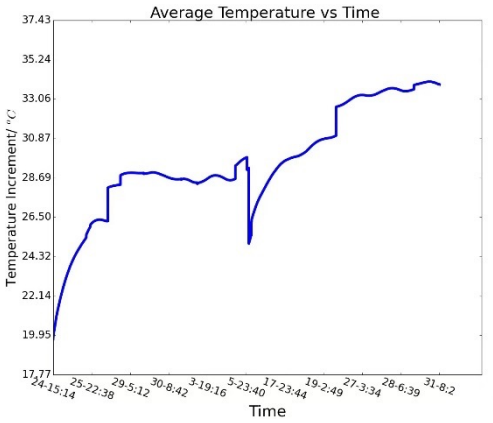
- To monitor the temperature variation of each SiPM, temperature sensors are placed on HBU.
- Only 16 sensors are used in each sub-HBU. These sensors are set in the some key points including the heat sources and the boundaries. By using some strategy, the temperature of each SiPM can be reconstructed.



Temperature sensor position



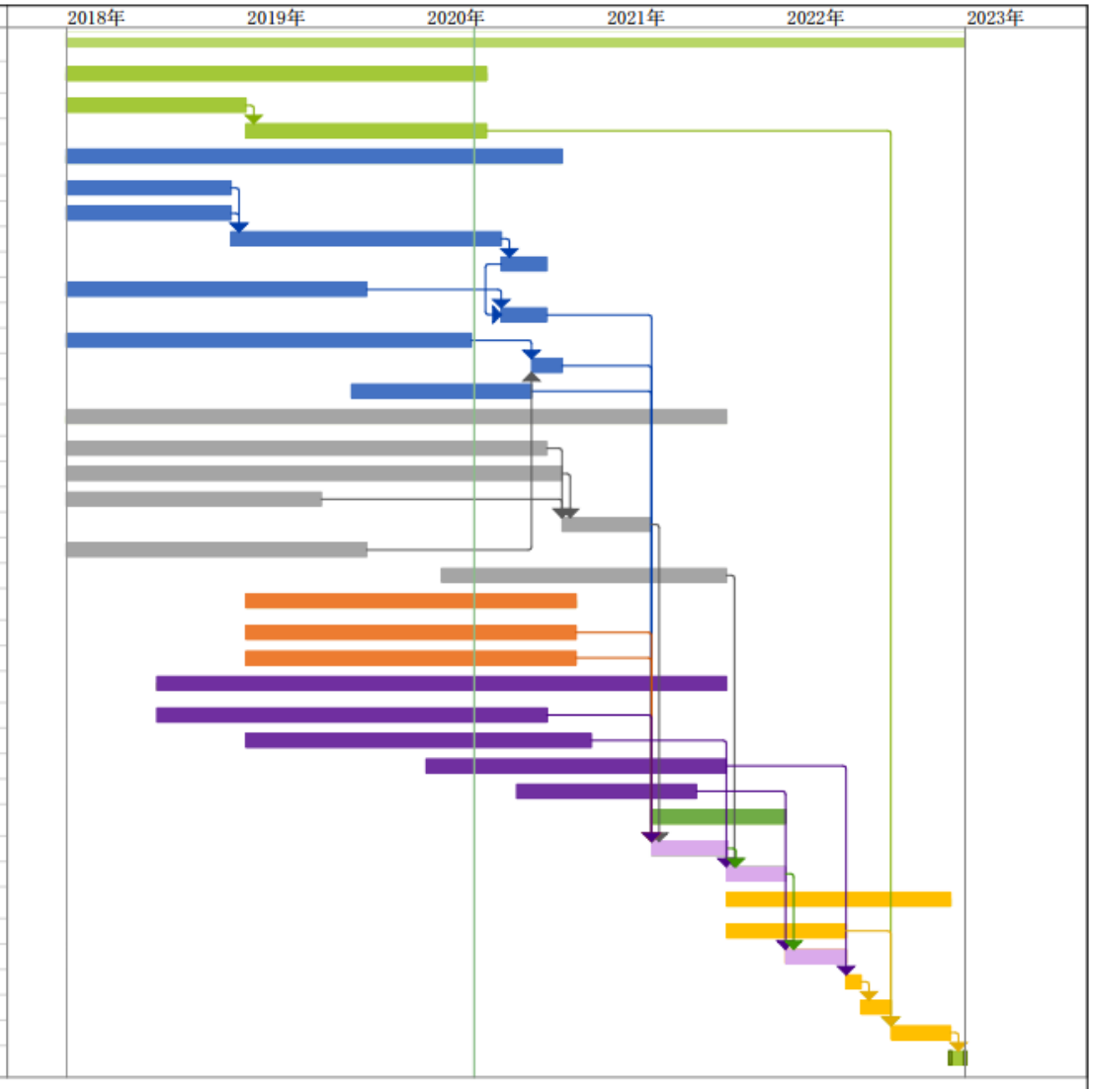
Temperature reconstruction results



Average temperature during beamtest

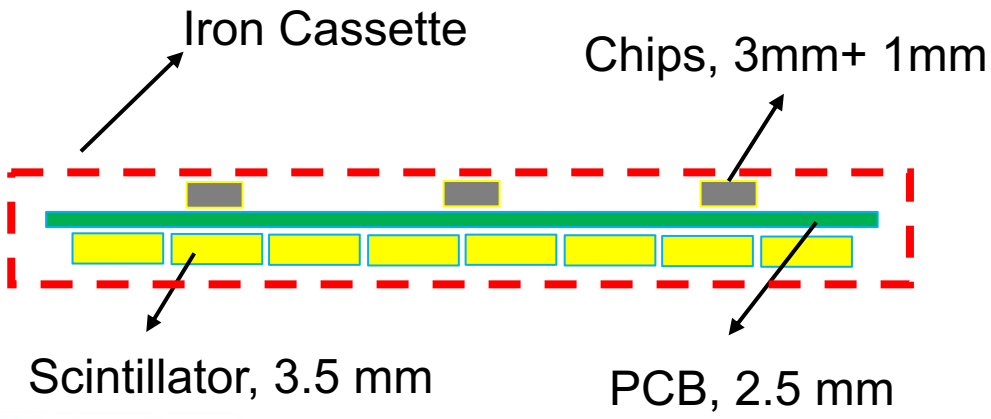
AHCAL R&D

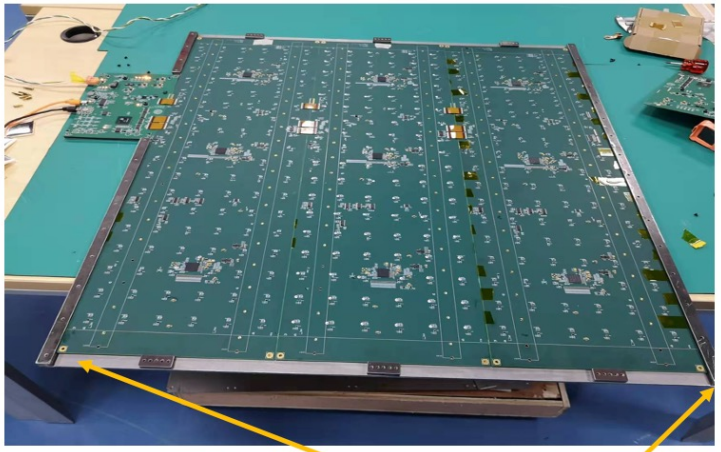
标识号	任务名称
1	**成像型强子量能器技术验证**
2	**1）量能器原型机物理设计**
3	1.1)量能器关键参数的选取和优化
4	1.2)量能器性能模拟研究
5	**2）灵敏探测器的研制**
6	2.1)原材料、器件采购
7	2.2)灵敏单元结构的设计和优化
8	2.3)闪烁单元生产工艺的研究
9	2.4)闪烁单元批量生产
10	2.5)闪烁单元包装工艺的研究
11	2.6)闪烁单元批量包装
12	2.7闪烁单元批量测试装置制作
13	2.8)闪烁单元批量测试
14	2.9)单层灵敏探测器工艺摸索
15	**3）读出电子学和数据获取系统**
16	3.1)原材料、电子元器件的采购
17	3.2)前端读出板和数据接口板的设计和开发
18	3.3)SPIROC芯片功能测试板开发
19	3.4)前端读出板和数据接口板的批量制作与测试
20	3.5)测试用数据获取板的开发与制作
21	3.6)数据获取板的开发与制作
22	**4）SiPM性能监测和刻度系统的研究**
23	4.1)基于LED的监测系统的开发
24	4.2)基于光纤的监测刻度系统的研究
25	**5）机械设计和制作**
26	5.1)探测器灵敏层结构
27	5.2)原型机吸收体和支撑结构
28	5.3)束流测试平台
29	5.4)宇宙线测试平台
30	**6）量能器原型机系统集成**
31	6.1)探测器灵敏层的组装和测试
32	6.2)整体样机的集成
33	**7）量能器原型机测试和性能研究**
34	7.1)数据分析软件的开发和准备
35	7.2)原型机宇宙线测试及质量检验
36	7.3)原型机束流测试前期准备和运输
37	7.4)原型机束流测试及样机运回
38	7.5)测试数据分析及原型机性能研究
39	8）项目总结



Sensitive Layer Cassette

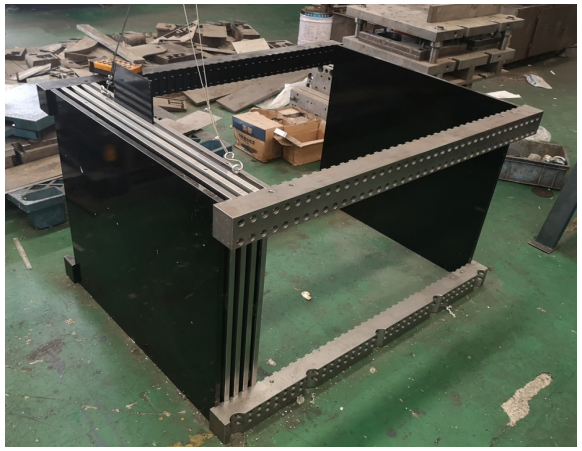
- To protect HBU, package it for testing and transportation purposes
- The cassette was made of iron to be part of the absorber layer
  - The size is 82.5 cm×76 cm
- How to ensure the flatness of the box is an important issue
- Select a whole iron plate for overall cutting, and avoid Hot-treat
- The support strips around are individually processed and fixed with screws





AHCAL main structure

- The main part of AHCAL supporting structure is iron absorber
  - There are 39 absorbers, and each size is about 84 cm×76 cm
- The absorber flatness is much crucial for the cassettes assemble
- Like the cassette design, select a whole iron plate with proper thickness for overall cutting, and avoid Hot-treat
- The thickness is not standard, So it is necessary to polish the iron plate to achieve the required thickness,
- Then use a leveling machine to calibrate the overall flatness



Summary

- In the past five years, after technological breakthroughs, a prototype of AHCAL has been developed
- Some highlights in the development process
  - Injection molding technology mothed for scintillator production
  - Trail new SiPMs from China
  - High integrated, embedded electronics board with multi functional
    - DAC, LED, temperature monitor..
  - Large size, high-precision mechanical design and processing

THANKS