Sci-W ECAL: R&D progress technical challenges for CEPC

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On behalf of CEPC calorimeter working group

Outline

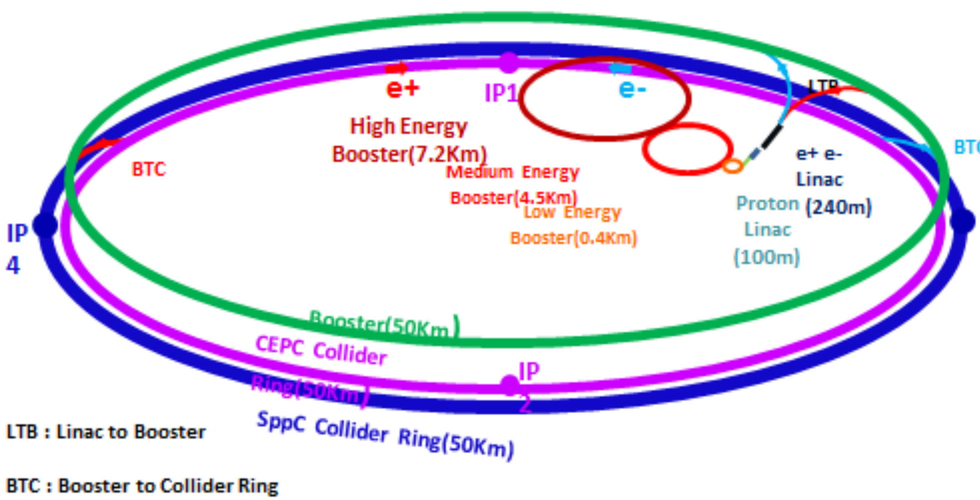
- Motivation
- PFA ECAL Progress based-on Sci-W
  - ShiShu Group
  - China Group
- Summary

Motivation

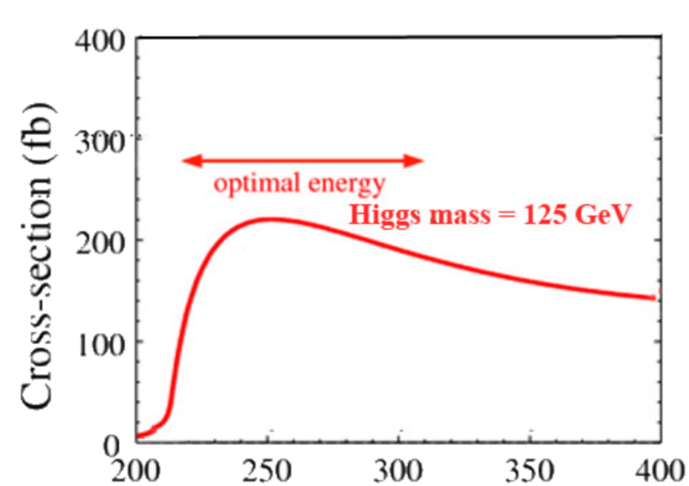
Circular Electron Positron Collider (CEPC)

$E_{cm} \approx 240$GeV, luminosity ~2×10^{34} cm^{-2}s^{-1} can also rum at the Z-pole

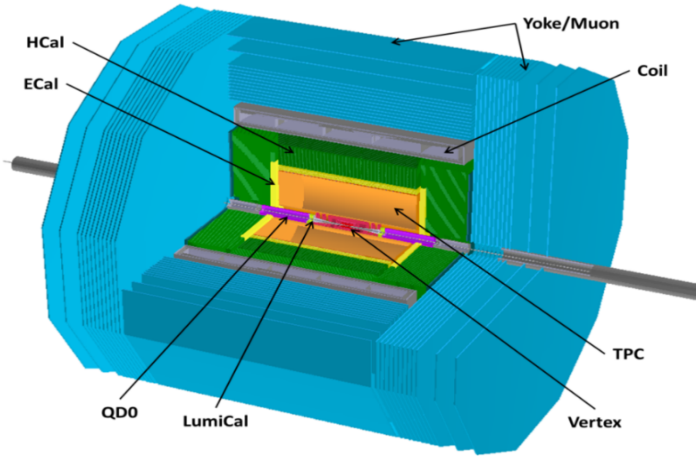
Precision measurement of the Higgs boson (and the Z boson)



$e^+e^- \rightarrow ZH$



Requirements of CEPC EMCal



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

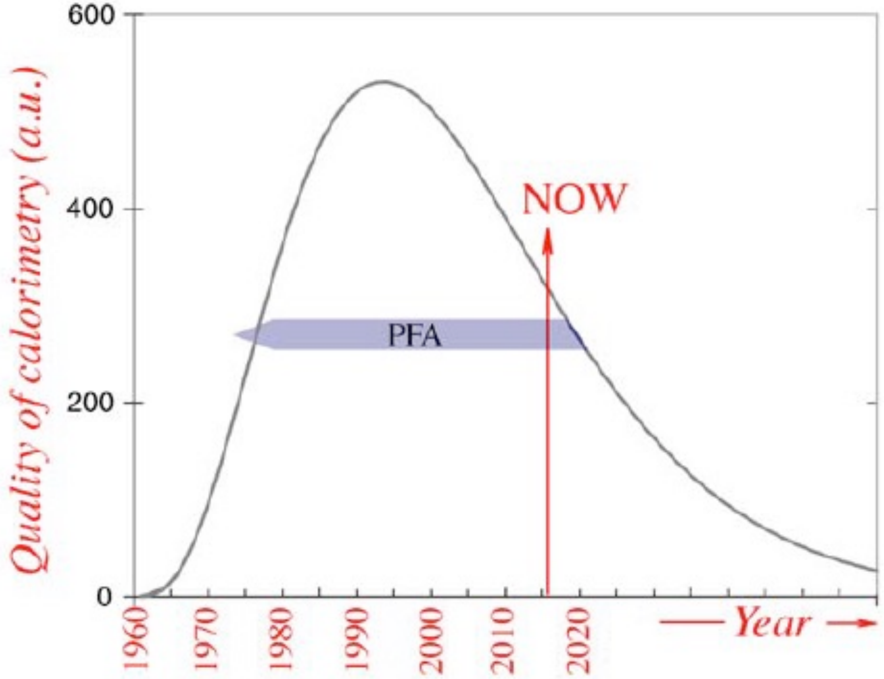
Challenges:

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

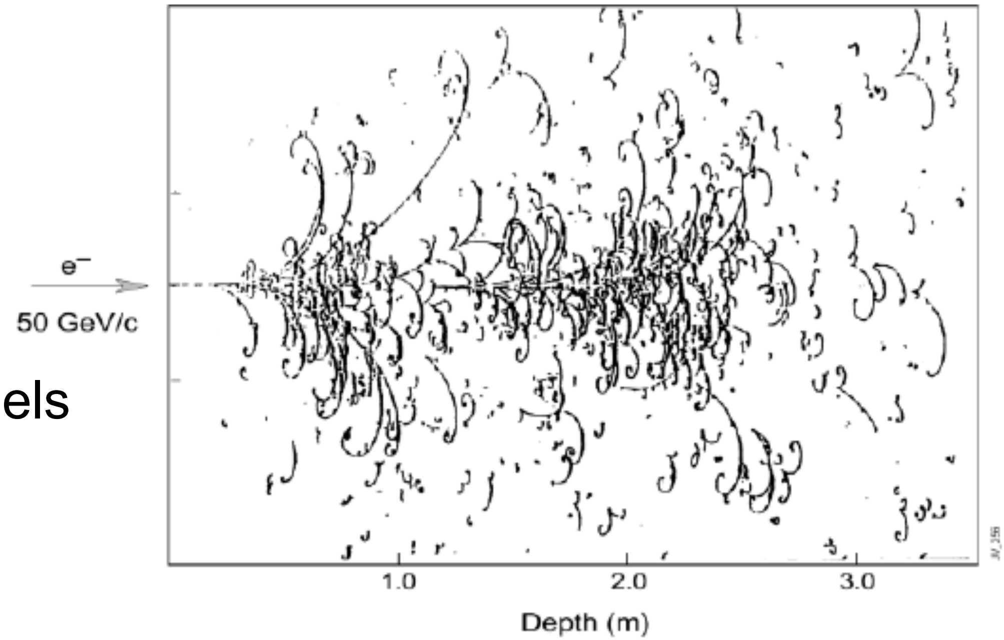
Calorimeter

- Calorimeter in HEP Experiment
  - Measure energy
  - Position/angle
  - Measure Time
  - Particle identification
  - Provide trigger



PFA Calorimeter

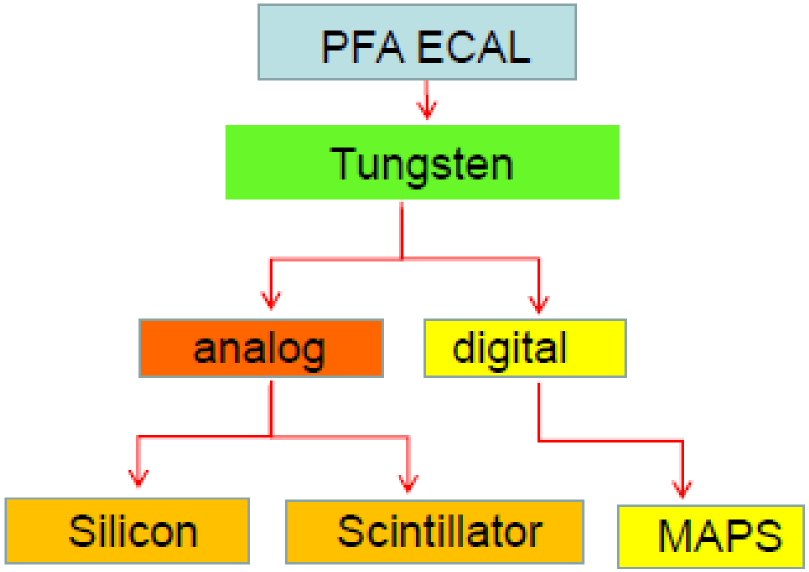
- Challenges
  - High granularity
    - ECAL ~10 million channels
  - Compact design
  - High power
    - ECAL about 100 kW
      - EBU: 80 kW (without power pulsing)
      - DIF: 20 kW

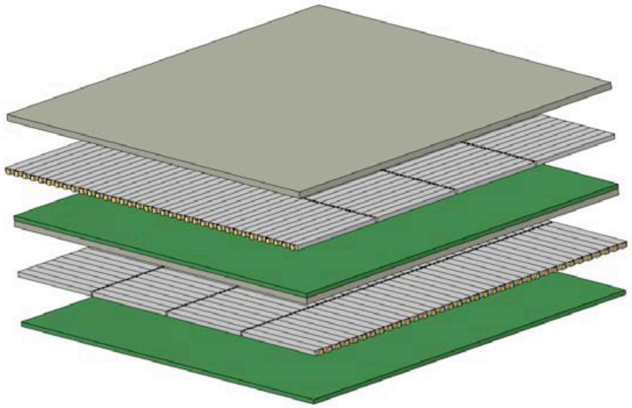


Big European Bubble Chamber filled with Ne:H_2 = 70%:30%, 3T Field, L=3.5 m, X_0≈34 cm, 50 GeV incident electron

Sci-W PFA ECAL of CEPC

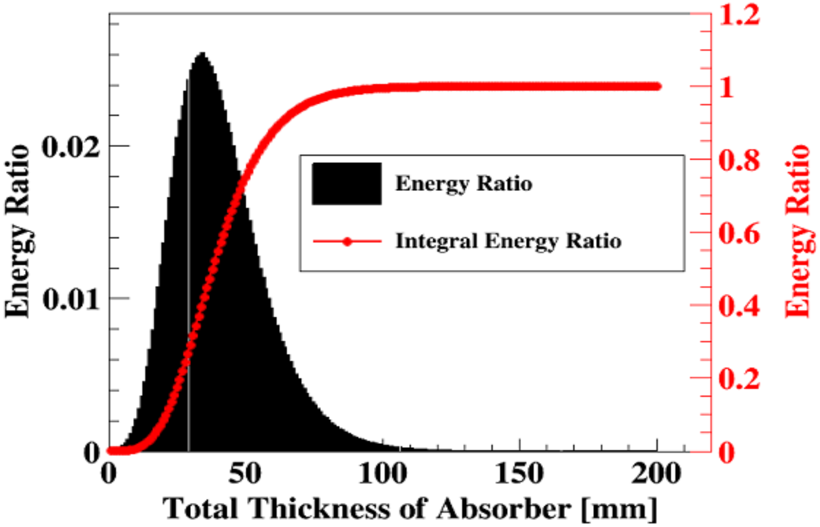
- Sampling Calorimeter
  - Sandwich structure
  - Absorber+SD+Electronics
- Absorber
  - Tungsten
- Sensitive Detector
  - Scintillator+SiPM
- Electronics
  - ASIC Chip

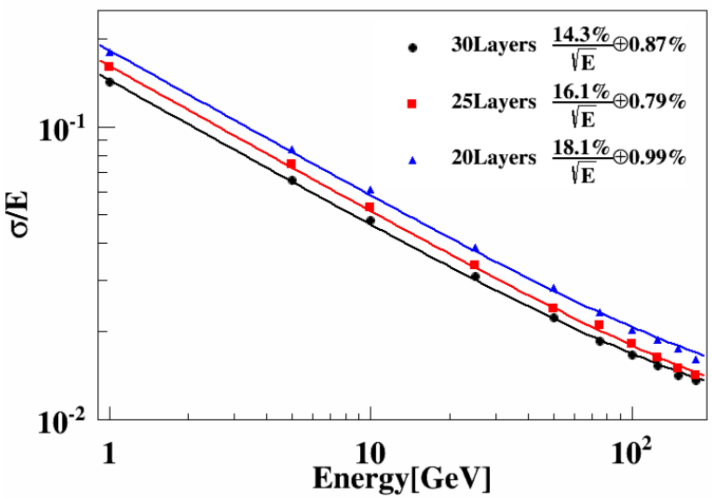


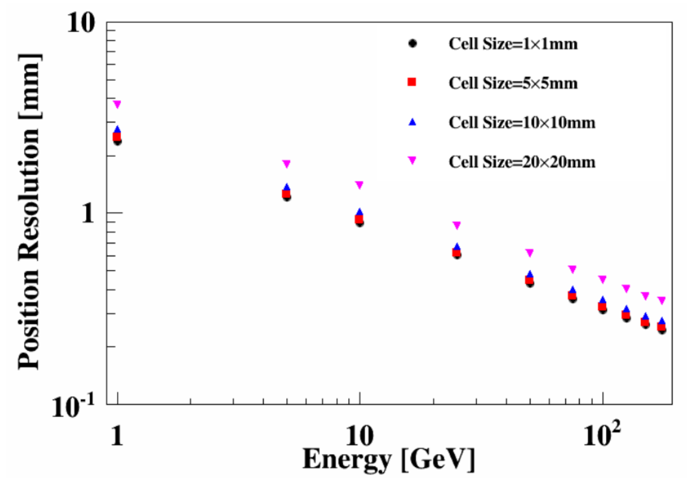


ECAL Optimization I

- Total thickness: 24 X_0
- Sampling number: 30 layers
- Granularity: <10mm*10mm

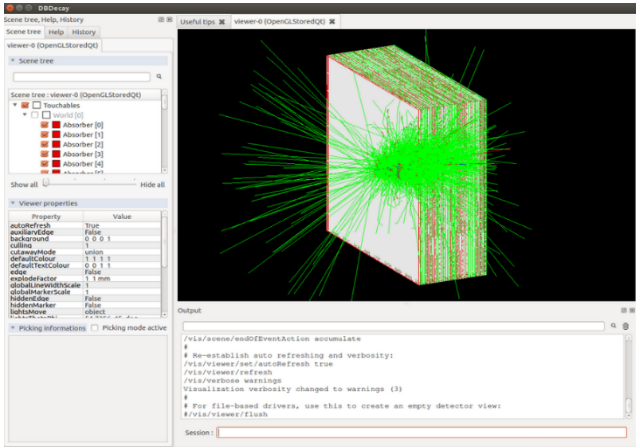


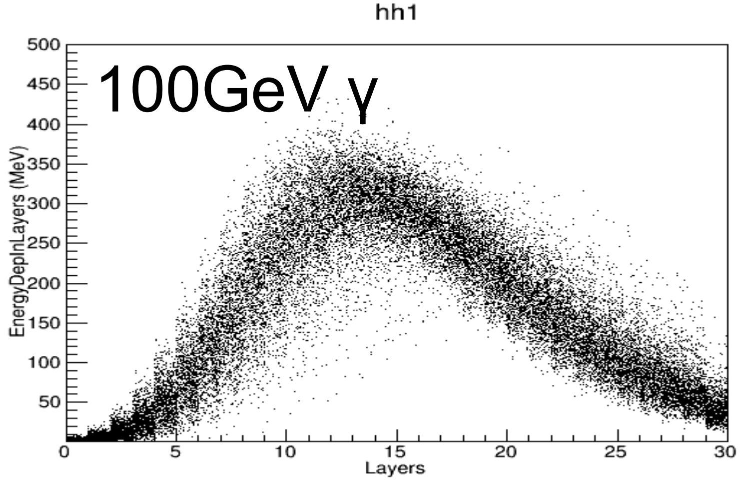




ECAL Optimization II

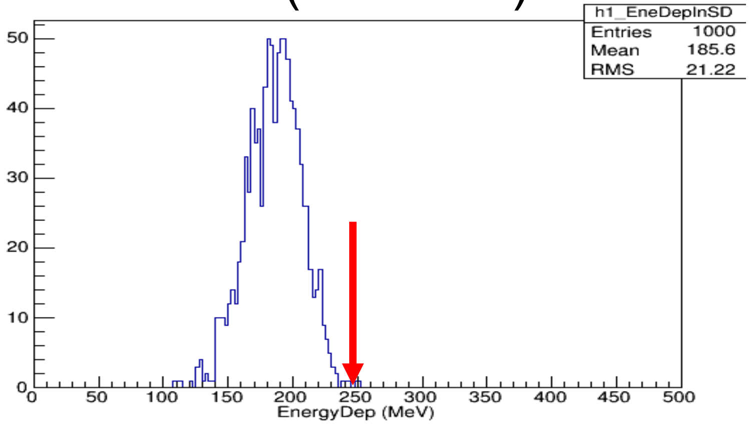
- Dynamic range of ECAL SD
  - 1MIP – 800 MIPs
- ~10 pe @ 1 MIP
  - SiPM ~10k pixels
- Gain of SiPM:~10^5
  - SPIROC:160fC – 100 pC





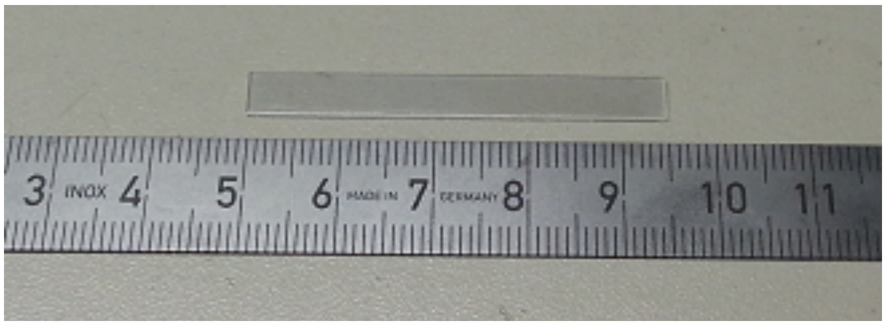
Shower profile in ECAL

240 MeV (800MIPs)

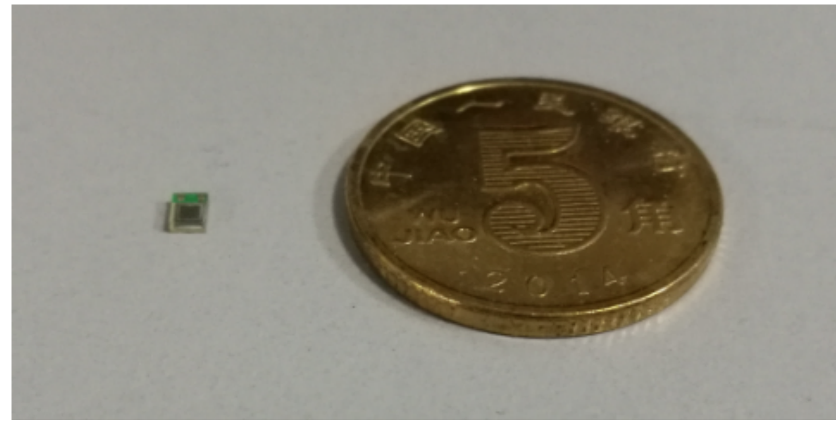


Max edep in SD

Elements of ECAL



Scintillator （5mm*45mm*2mm）



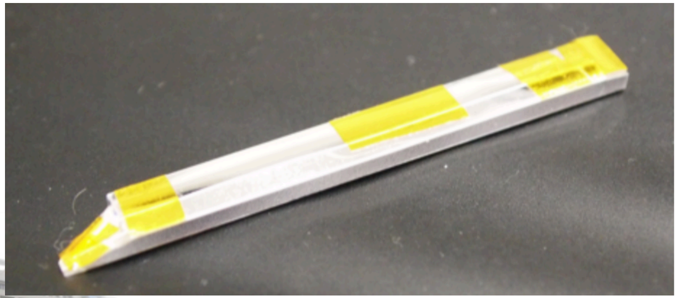
SiPM（1mm＊1mm, 10k pixels）

- Dynamic range： ~100fC~200pC
- channels： 36
- Dead time： 2ms
- Polar: positive
- power： 8mW/channel

Scintillator

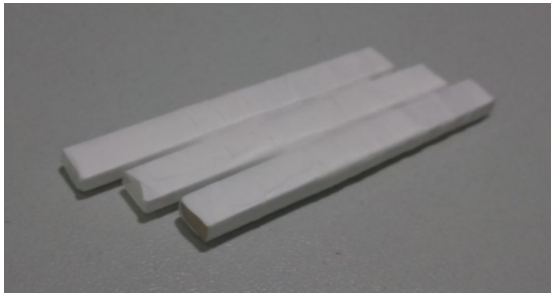
Shinshu Group

- EJ-204
  - LO：64%
  - Rise time：0.9 ns
  - Decay time：2.1 ns
  - Wavelength：425 nm
  - Att Length：210 cm



China Group

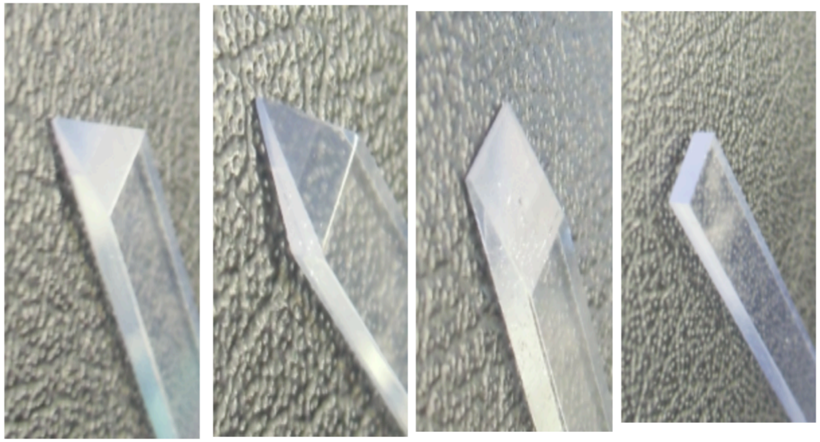
- BC-408
  - LO：64%
  - Rise time：0.9 ns
  - Decay time：2.1 ns
  - Wavelength：425 nm
  - Att Length：210 cm



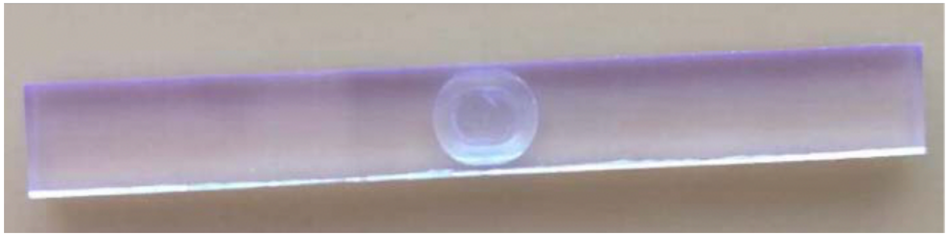
Scintillator

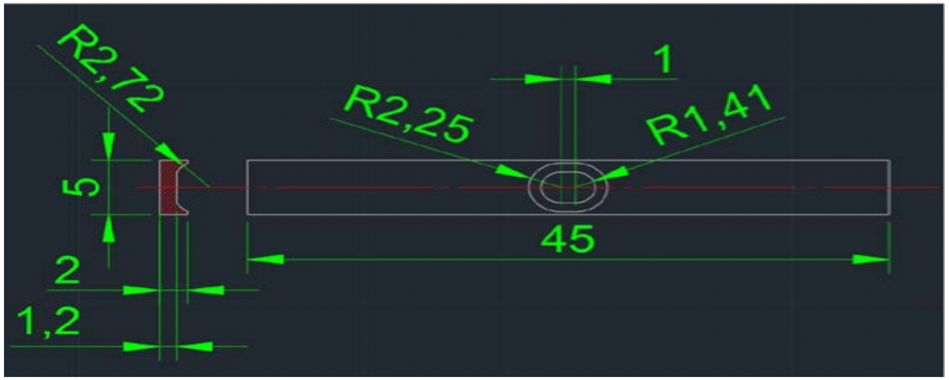
Shinshu Group

China Group



Different wedge design



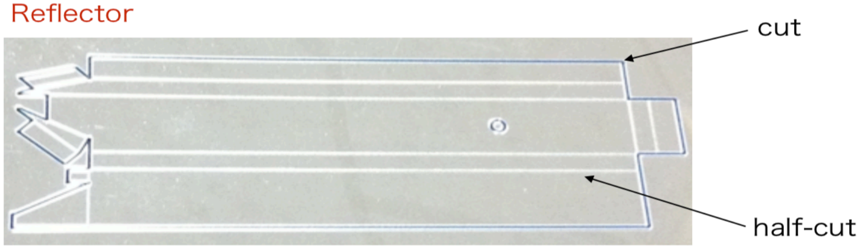


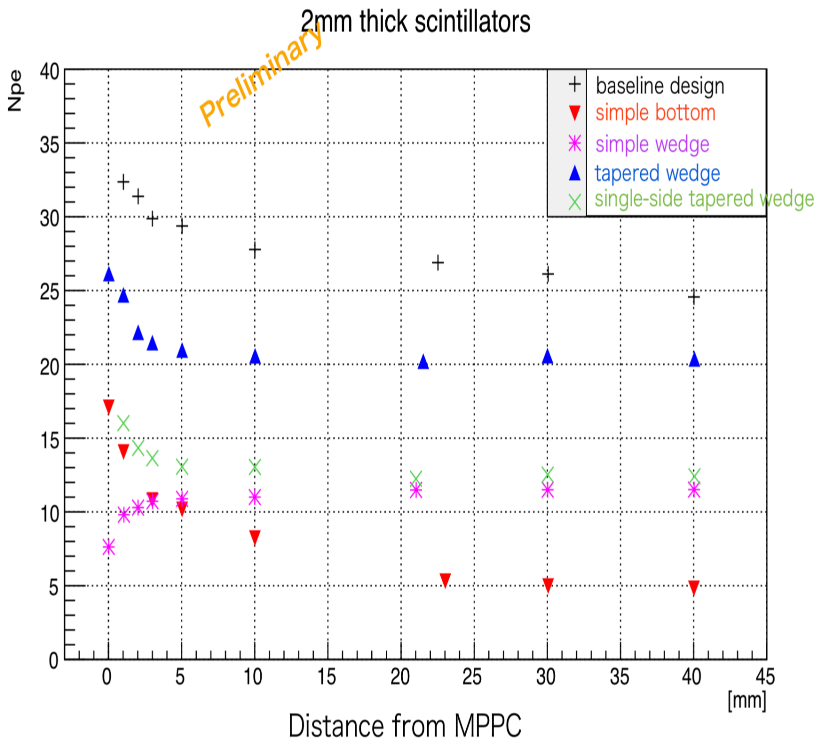
Trench design

Scintillator

Shinshu Group

We made reflectors by laser cutting.
Laser cutting enable us easier wrapping.

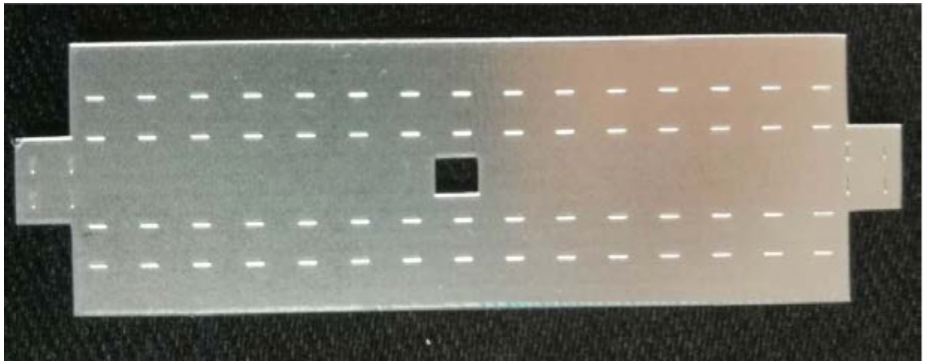


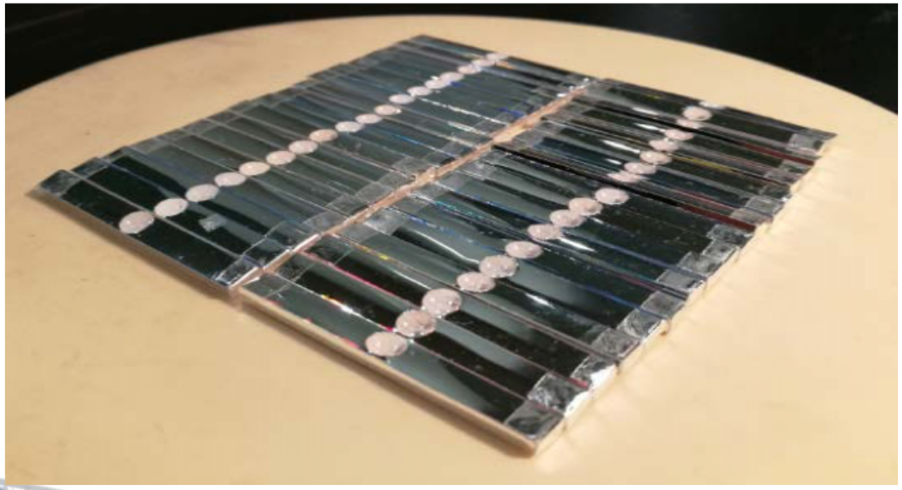


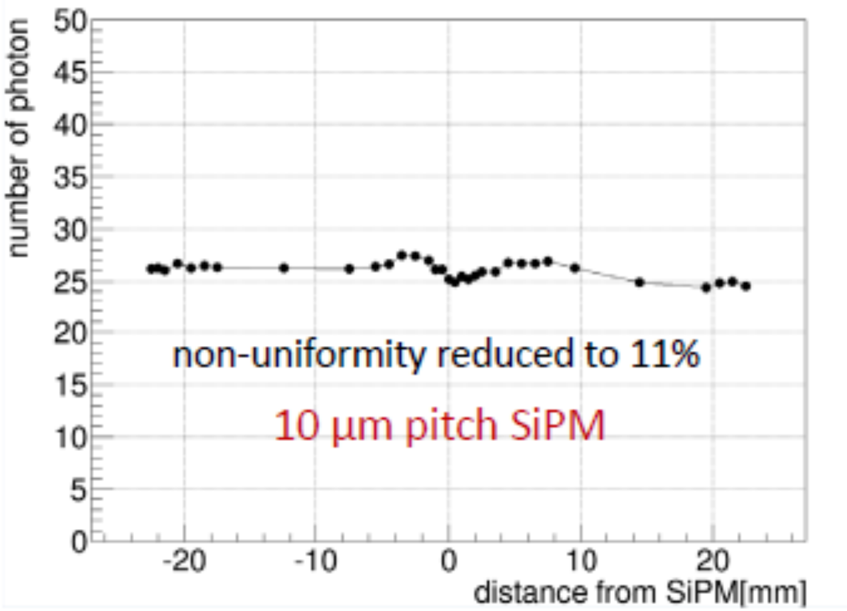
The light collection uniformity

Scintillator

China Group







The light collection uniformity

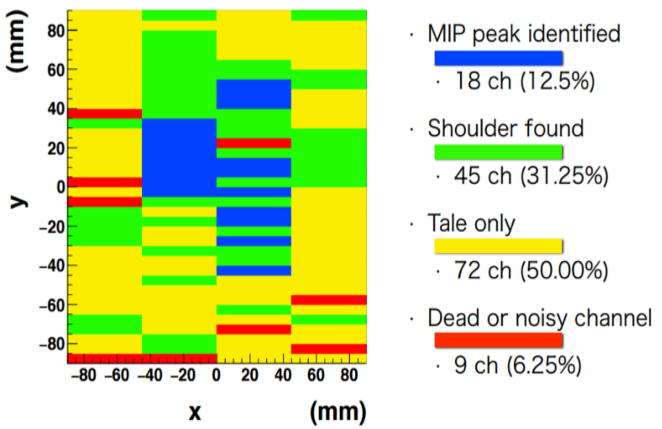
SiPM

Shinshu Group

Three different types SiPM were or will be used

MPPC : 1600pix. 1mm x 1mm
HAMAMATSU, S103692-11-025P (Old type)

We gave up 1600pix. MPPCs because of bad S/N.
We guess this problem is coming from combination of S
1600pix. MPPC.

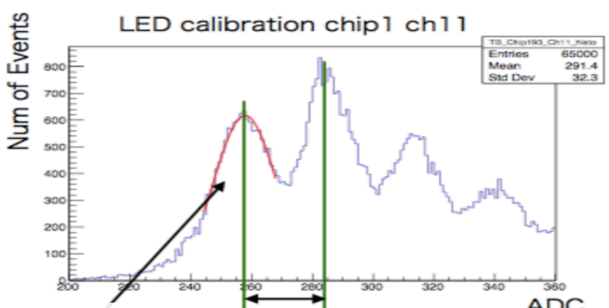


- Peak identified channels are only 12.5%.
  MIP peak identification with 10k pixel MPPC is not easy.

MPPC : 10k pix. 1mm x 1mm
HAMAMATSU, S12571-010P, 108 channels

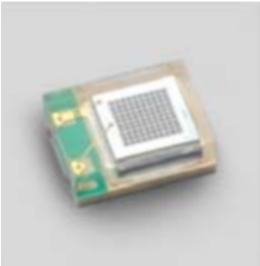
We couldn't see good SPS with 10k pix. MPPC.
The problem is maybe not the low gain but noise coming from MPPC.

Pixel: 15um

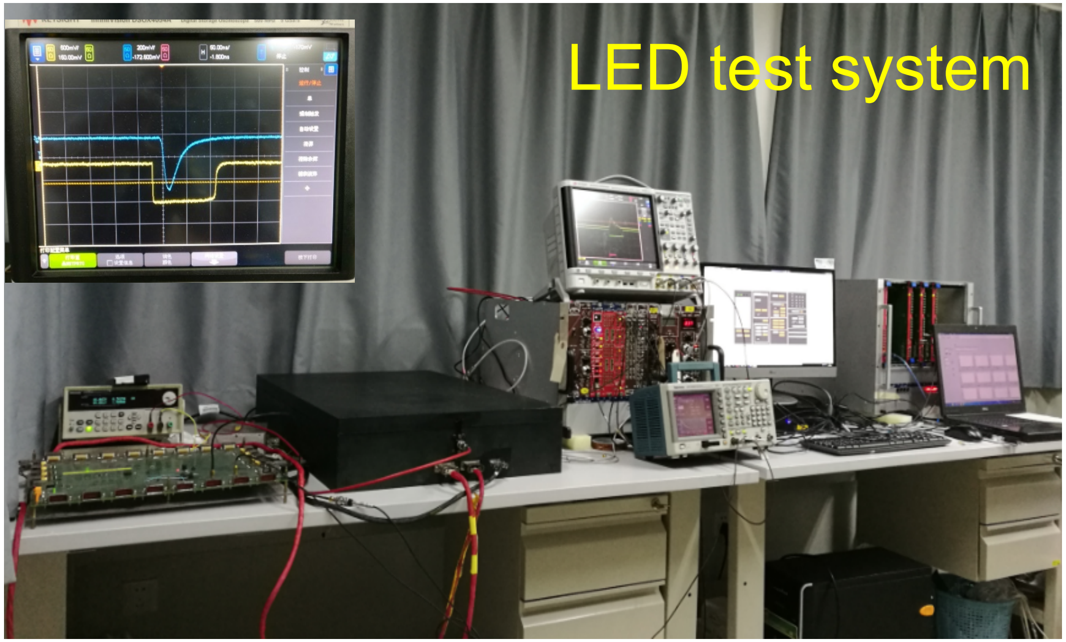


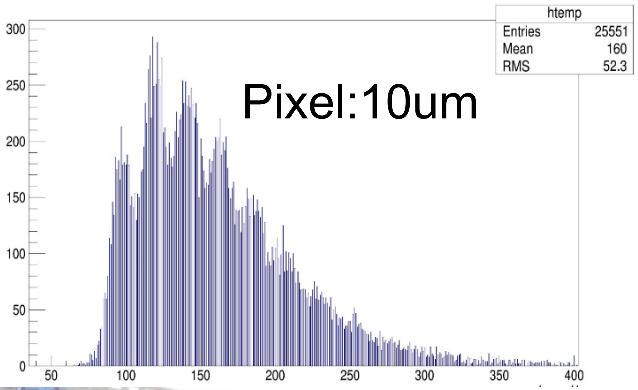
SiPM

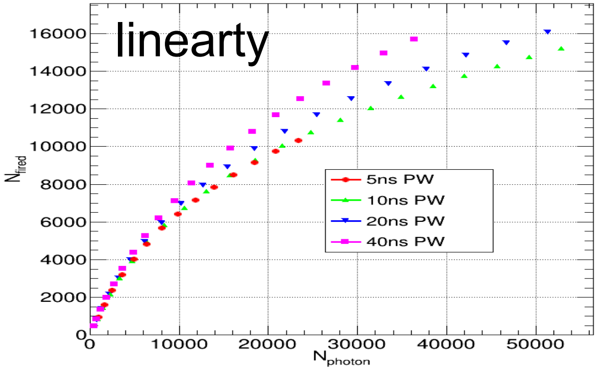
China Group

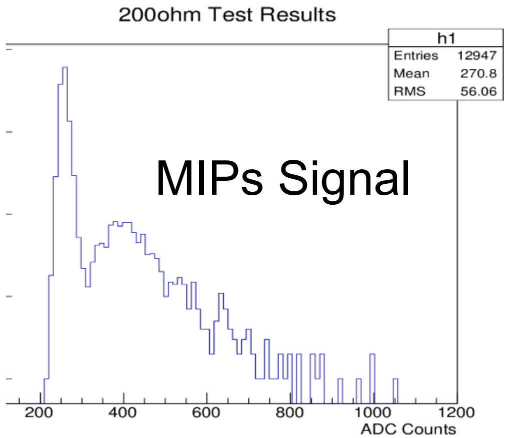


Size： 1 mm * 1 mm
Pixel size: 10 um * 10 um
pixelNo. : 10,000





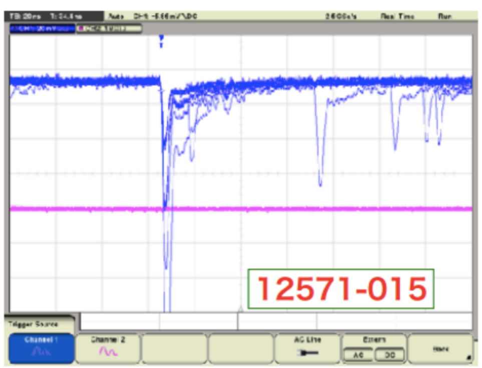




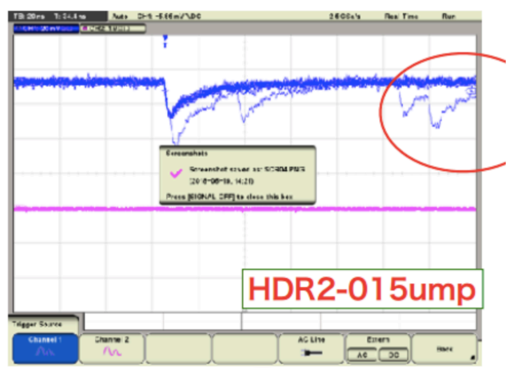
New SiPM

From Shinshu group report

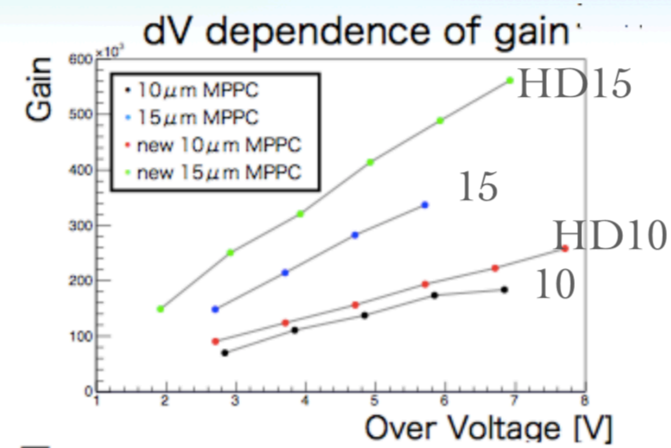
- HPK announced new types of MPPC
- 10um & 15um pitch MPPC
  - with trench technology : HD
    High Dynamic range
  - to reduce cross talks
- we have got two types from HPK
- 10 & 15 um pitch

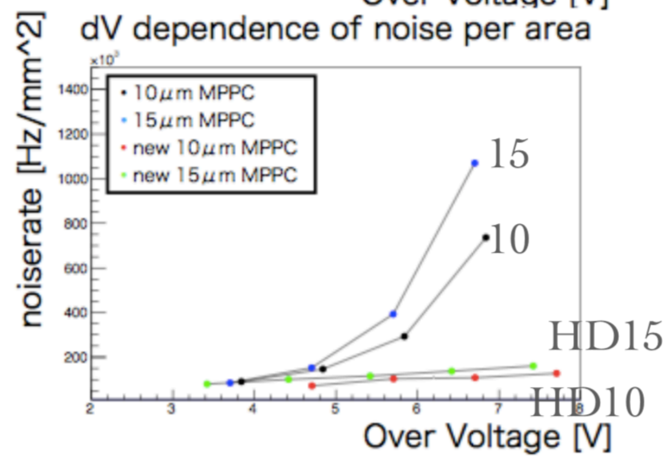


20mV&20ns



20mV&20ns

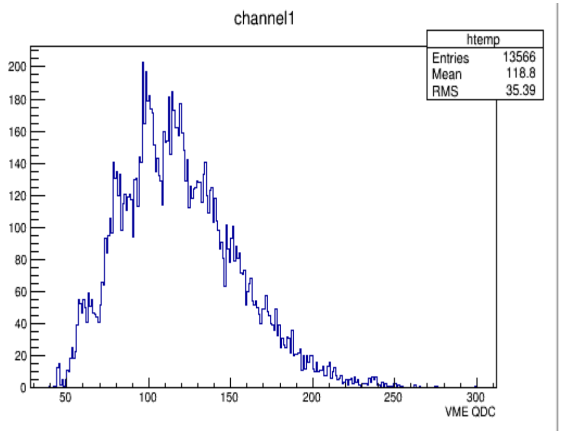




Measured with CAMAC readout

New SiPM

From China

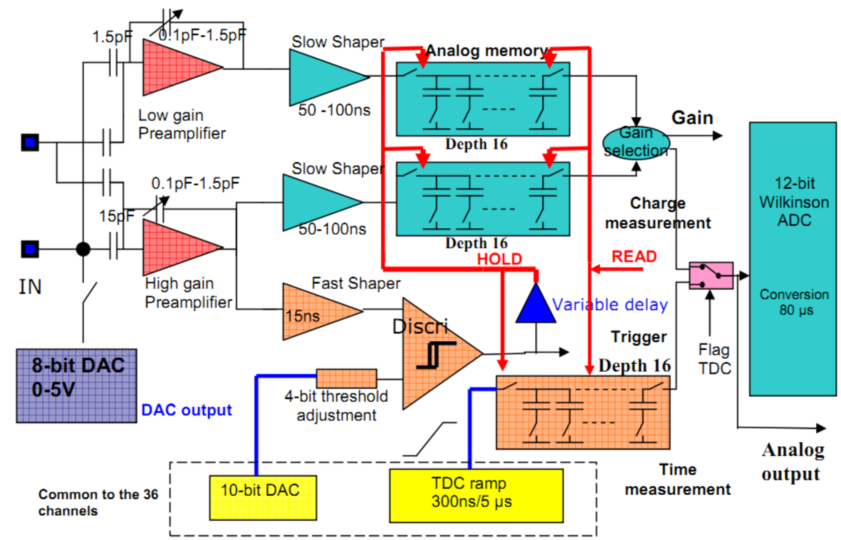


Parameter	NDL	HAMAMATSU
Effective area （mm^2）	1×1	1×1
Pitch size（um）	10	10
Pixel No.	10000	10000
Break down voltage (V)	27.5±0.4	65±10
PDE（%）	31	10
Dark Count rate（kHz）	500	100
Temperature Coefficient for V_b （mV/°C）	25	60
Gain	$2.0*10^5$	1.3×10^5
SPE Time resolution* （ps）	70	300

Readout Electronics

- SiPM front-end with **ASIC**

  SPIROC2b/SPIROC2e of 36 channels
- Switched capacitor array store charge measurement
- 12 bits ADC conversion
- Variable Gain due to:
  - adjustable C_f of pre-amplifer
  - R_{load} on the board
  - Shaping time and delay



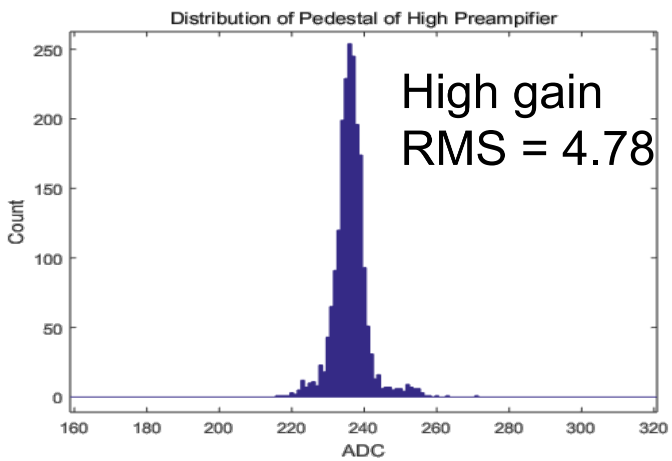
SPIROC2B

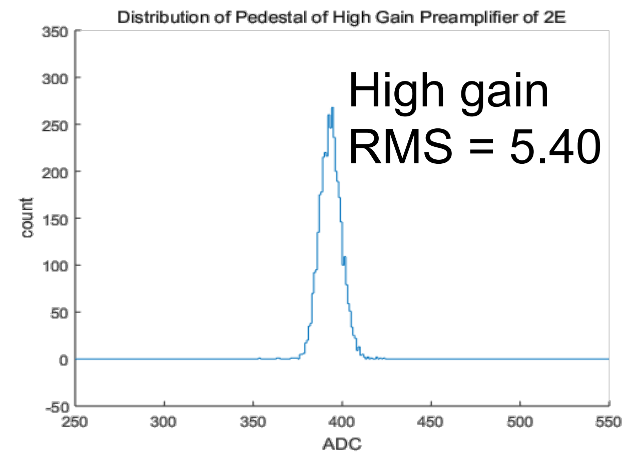
SPIROC2E

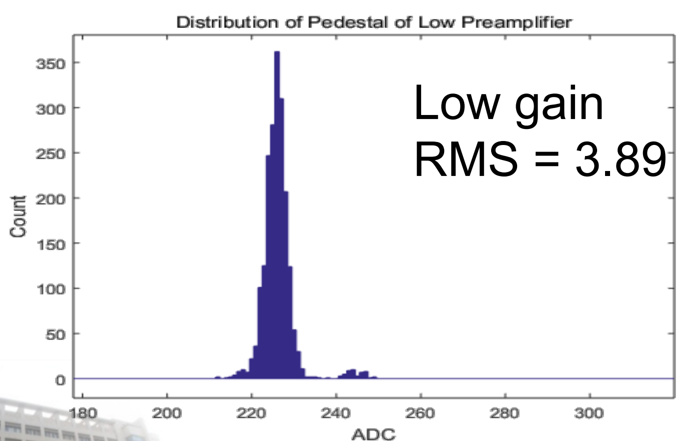
Pedestal of SPIROC2b/2e

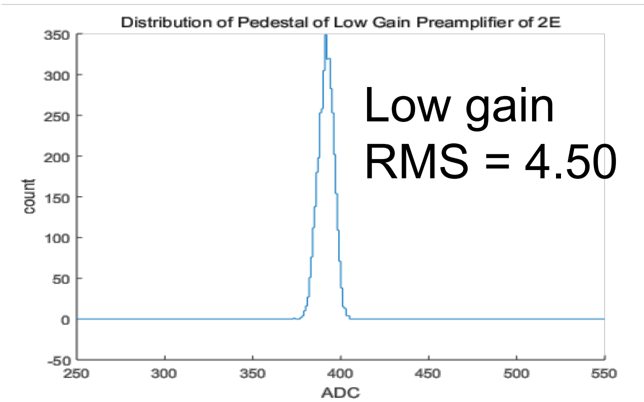
SPIROC2b

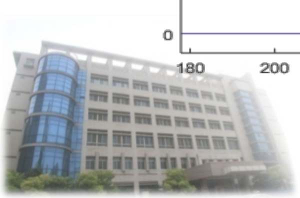
SPIROC2e





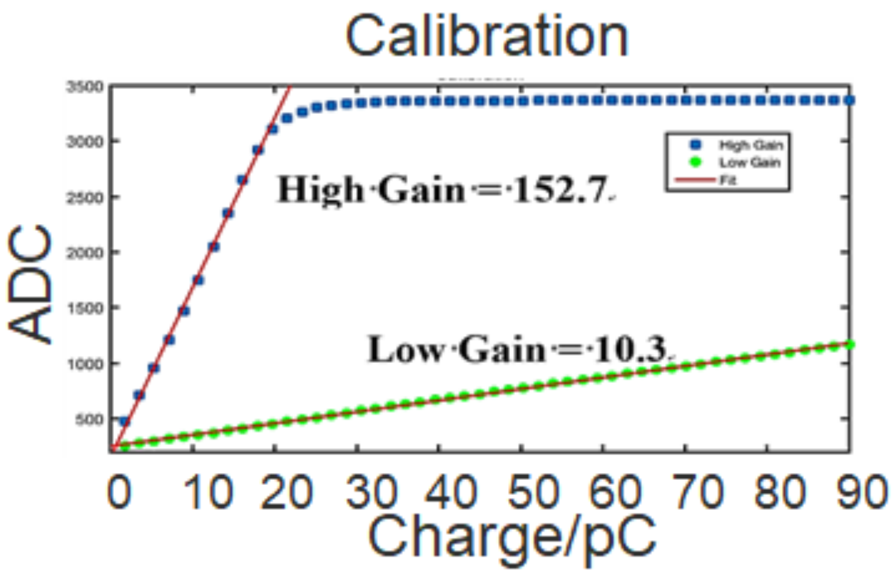




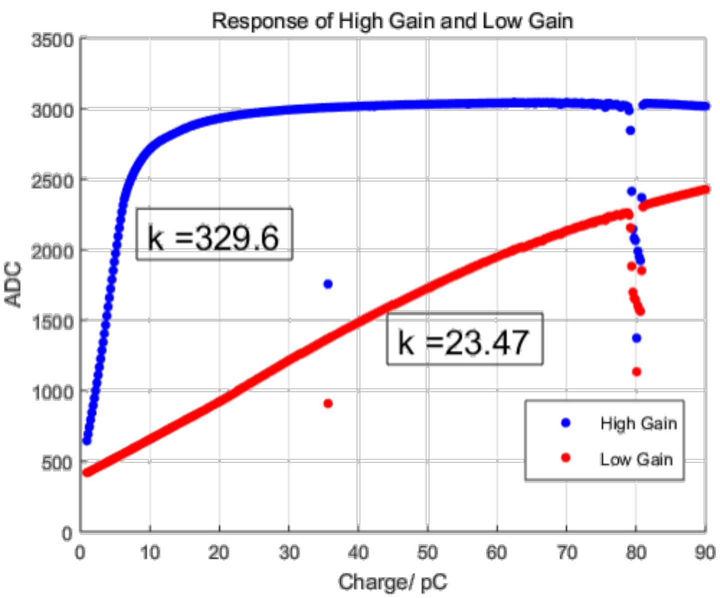


Dynamic range of SPIROC2b/2e

SPIROC2b

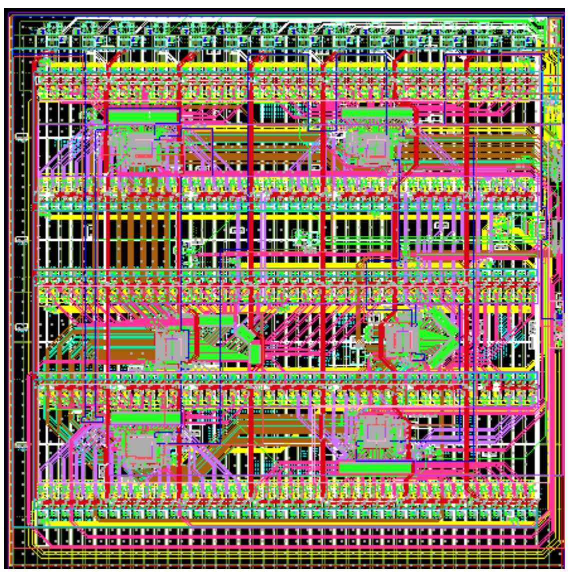


SPIROC2e



Thinning PCB Producing

- PCB
  - Thickness: 1.2mm
  - Num. of Layers : 14



兴森科技
FASTPRINT

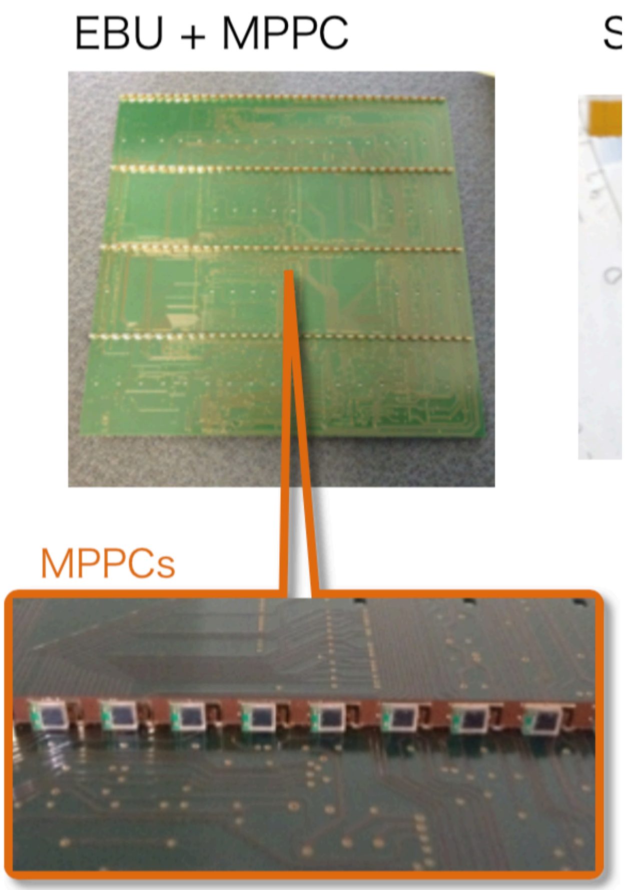
Thinning Device

Subsystem	Device	Height
Global	Tantalum Cap. F950 Series	0.8mm
Connector	Hirose FFC-FPC	1.2mm
	Power Connection BB02	0.75mm
Calib. System	DAC TLV5618A	1.75mm
	REF ADR1581	1mm
	Buffer AD8591	1.45mm
	MOSFET Driver UCC27524	1.75mm
Temp. Monitor	Temp. Sensor TMP117	0.8mm
	I2C Switch PCA9548A	1.2mm

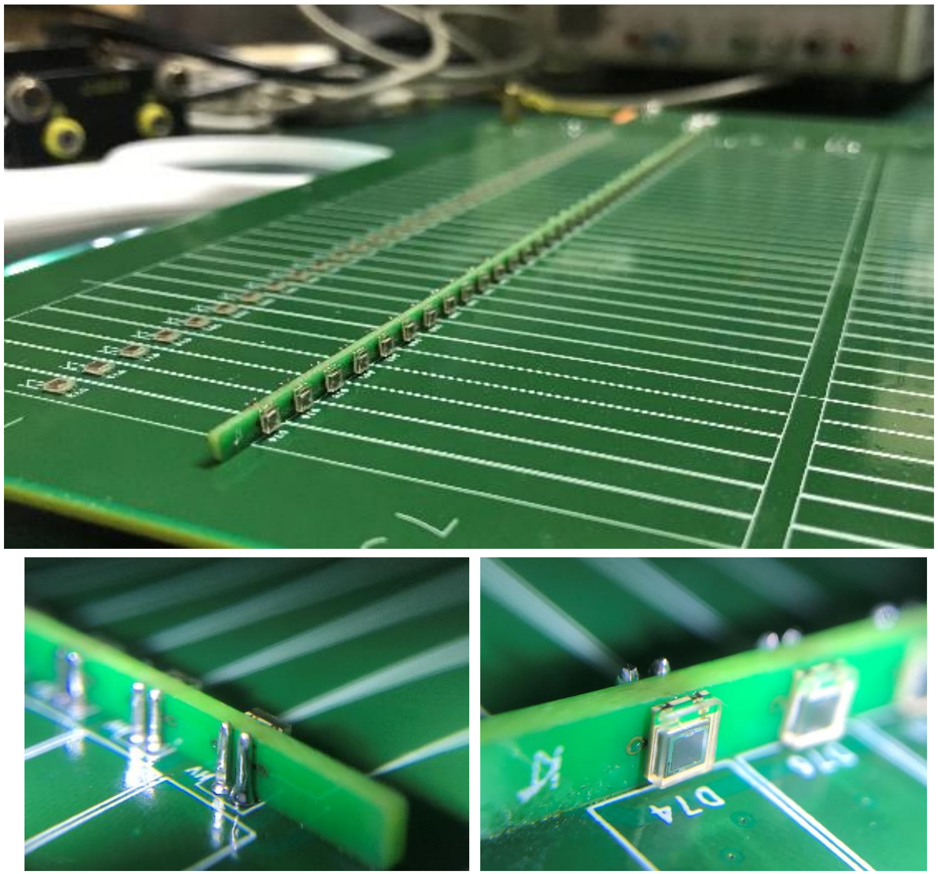
Totally 2.95mm thickness including electronic devices

Readout Electronics Board

Shinshu Group

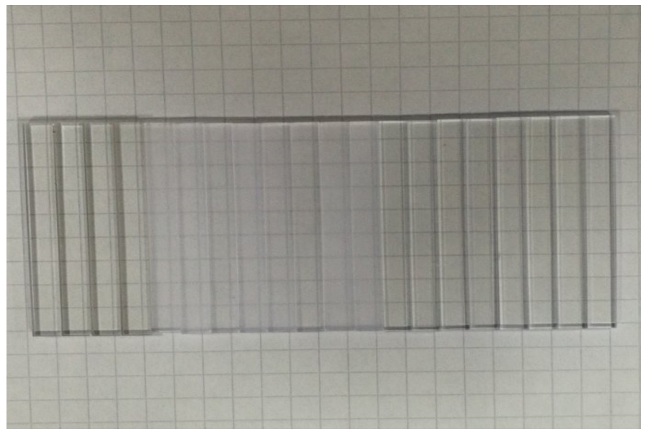


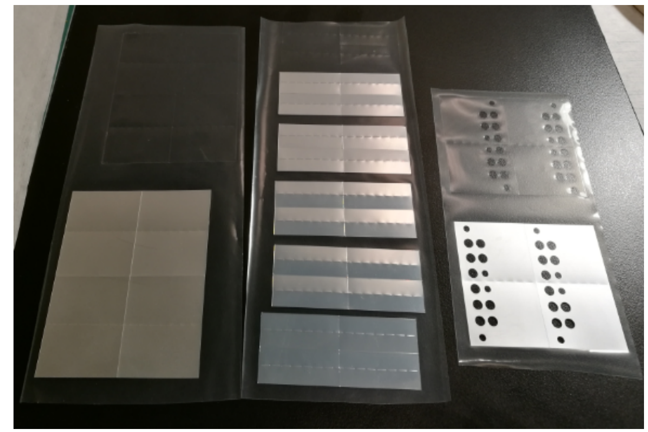
China Group

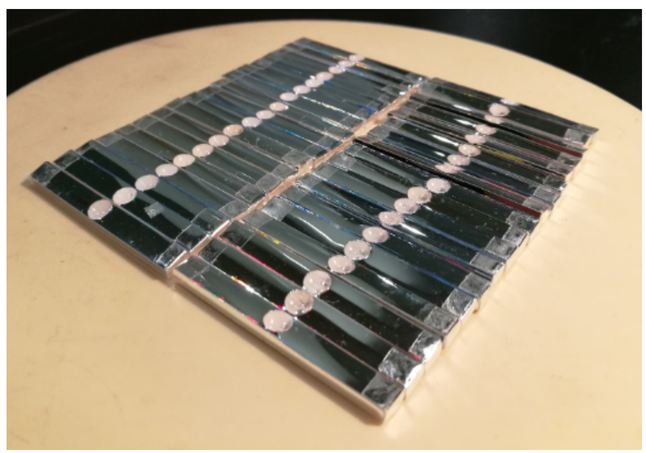


Single Layer Prototype

1. Cutting
2. Grooving
3. Polishing
4. Annealing
5. Cleaning
6. Packing







Single Layer Prototype

Visual inspection

Size measurement

cleaning

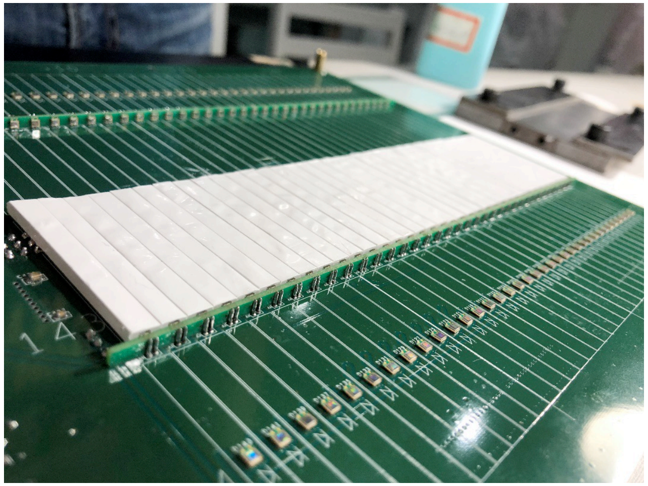
assembling

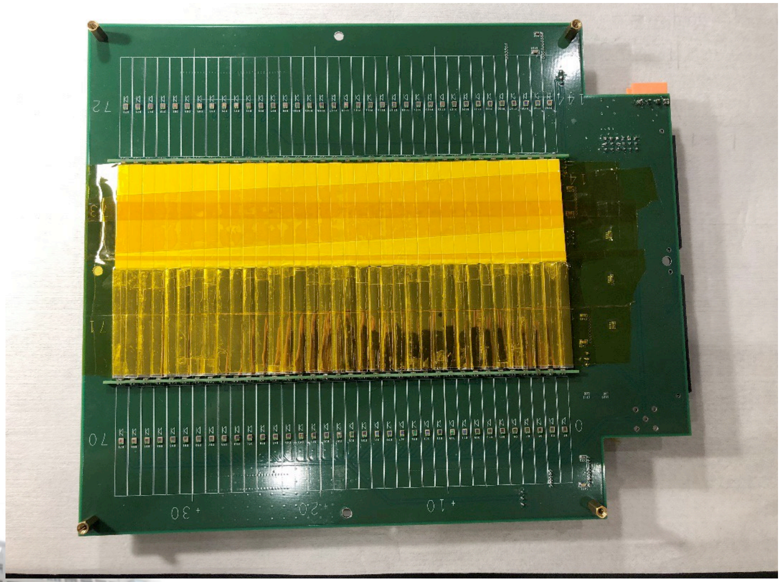
The single layer prototype was assembled in Shanghai Institute of Ceramic (SIC)

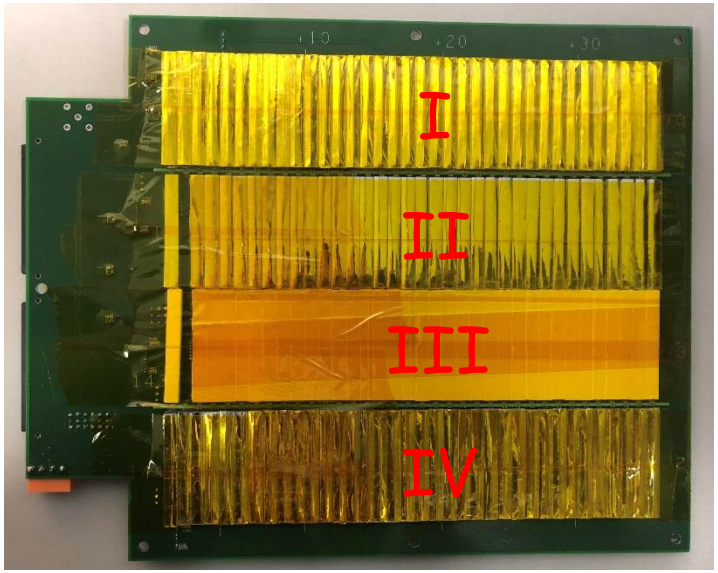
Since 1928 SICCAS

Single Layer Prototype

- 144 modules of scintillator strip coupling with SiPM (S12571-010P)
- I and IV: bottom-center embedded coupling mode, wrapped with ESR
- II: Side-end coupling mode scintillators wrapped with ESR
- III: Side-end coupling mode scintillators wrapped with Teflon

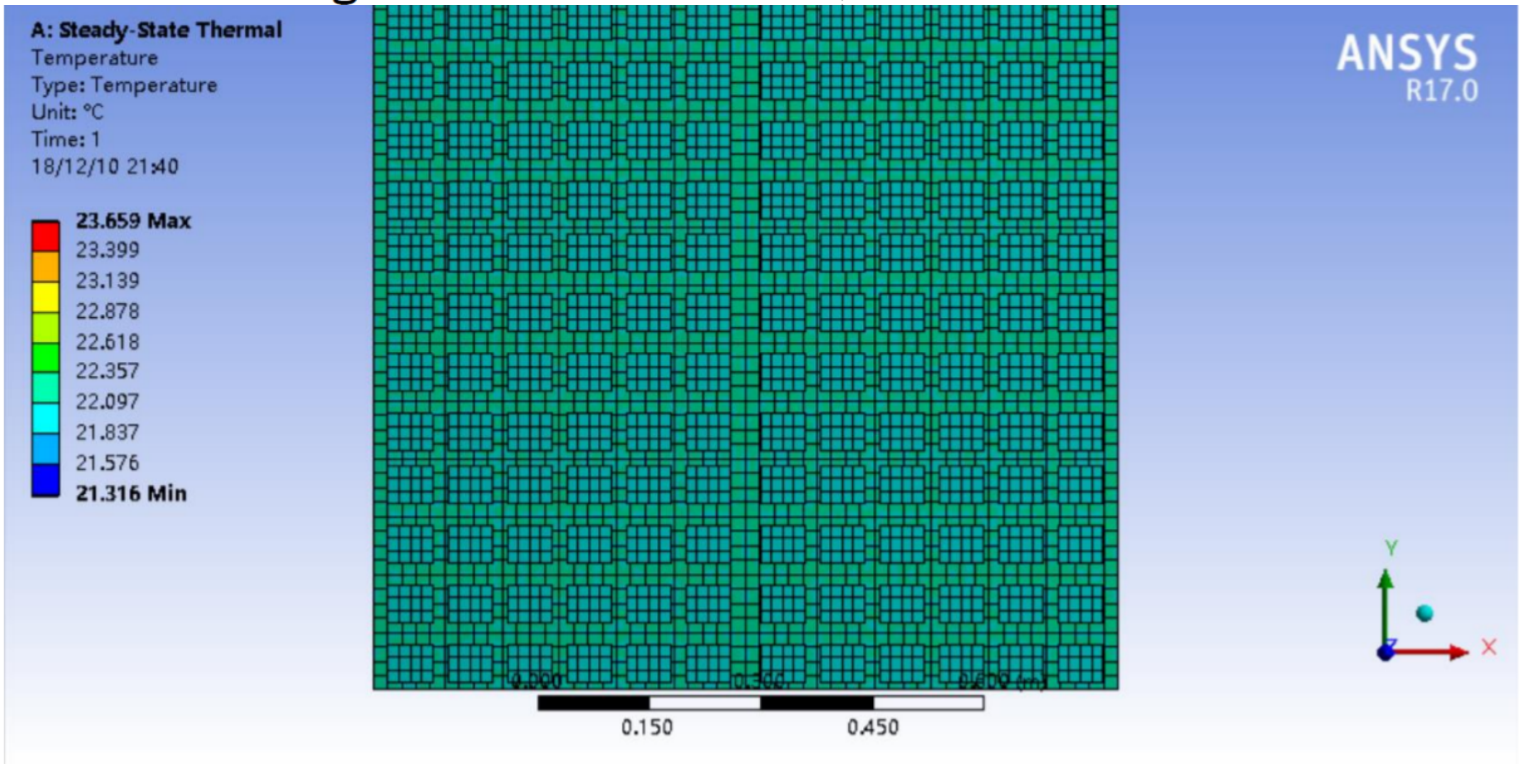






Cooling is under studied

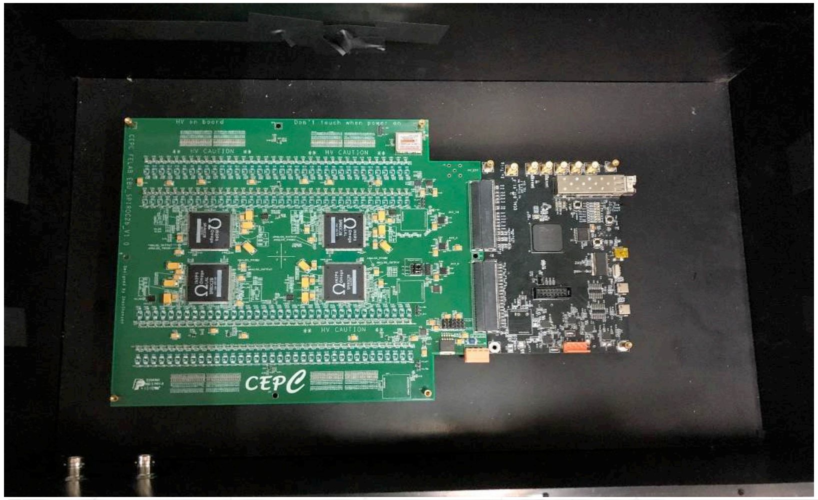
- CEPC is designed to operate at continuous mode with beam crossing rate: 2.8×10^{5} Hz. Power pulsing will not work at CEPC.
- Compare to ILD, the power consumption of VFE readout electronics at CEPC is about two orders of magnitude higher, hence it requires an active cooling

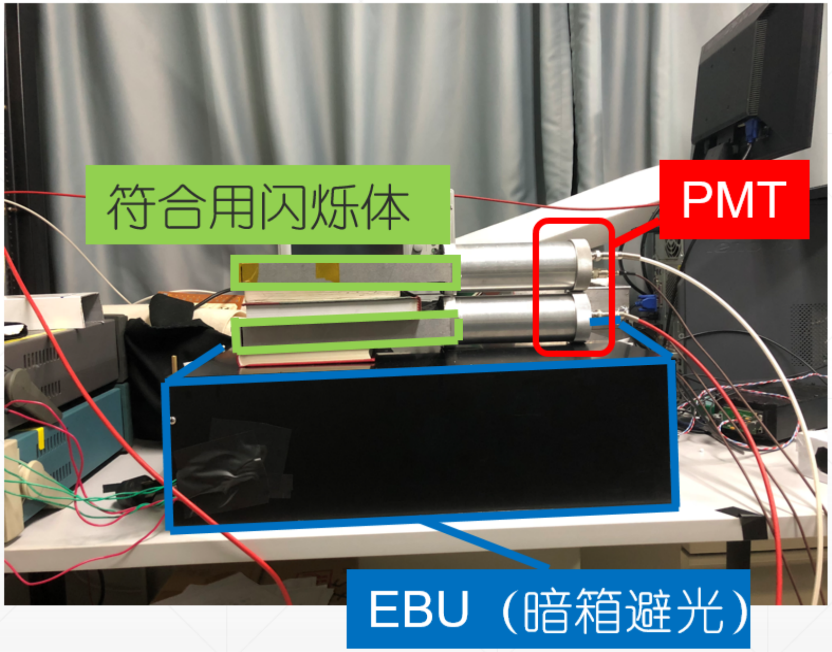


Rectangle pipe, water temperature: 22℃

Single Layer Prototype

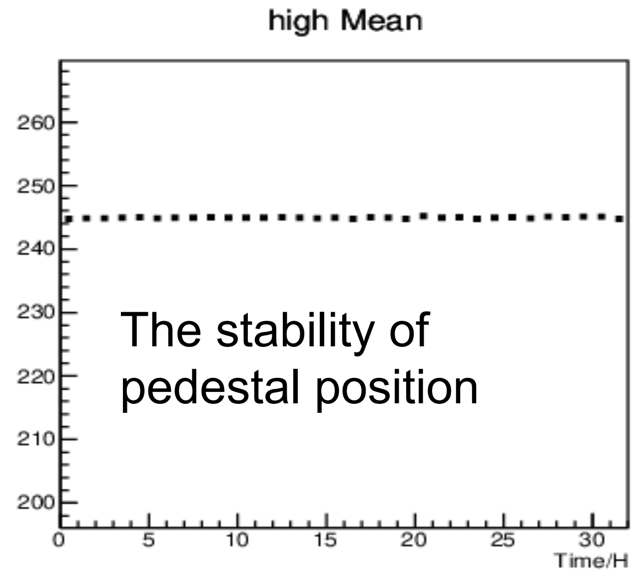
- Cosmic Ray Test
  - The telescope was composed of two plastic scintillators which with size of 20 cm * 20 cm.
  - The FEB and DIF boards were put in the dark box
  - The noise of each channel could be tested and stability could be monitored
  - The response to cosmic ray of each channel could be tested and could be used to evaluate the different wrapped and coupled methods.

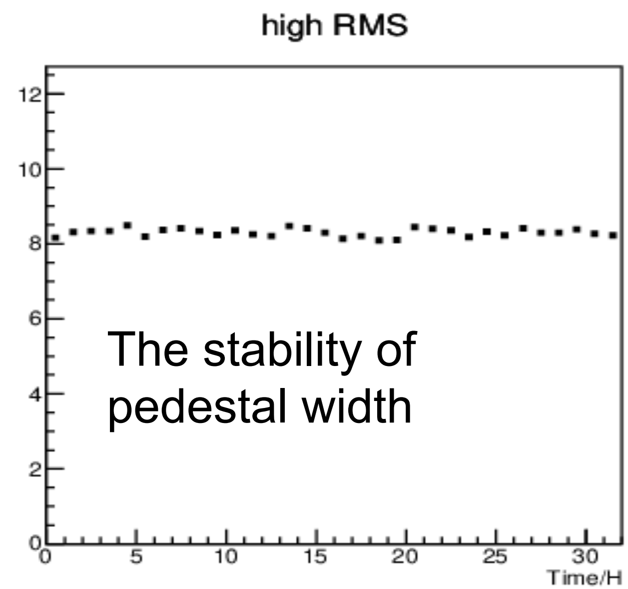


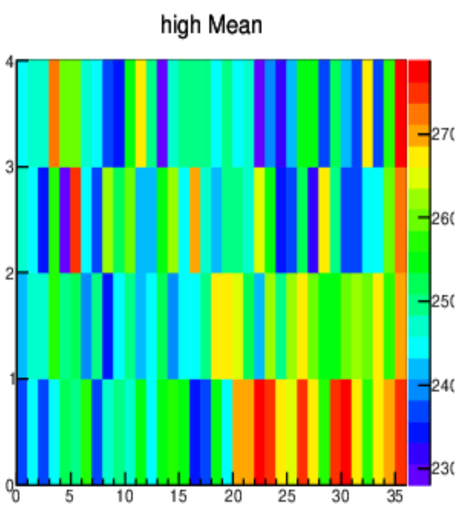


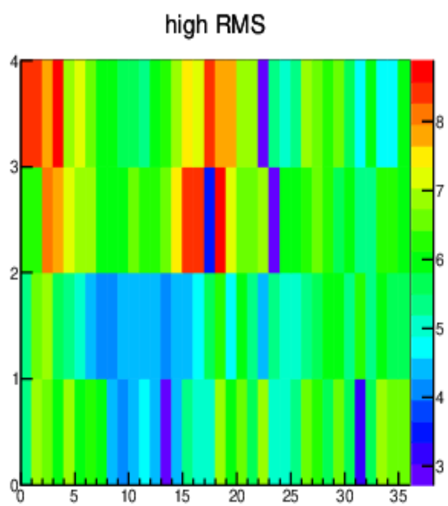
Electronics performance

- Working in high gain mode
- SiPM with H.V.
- Long time work stability

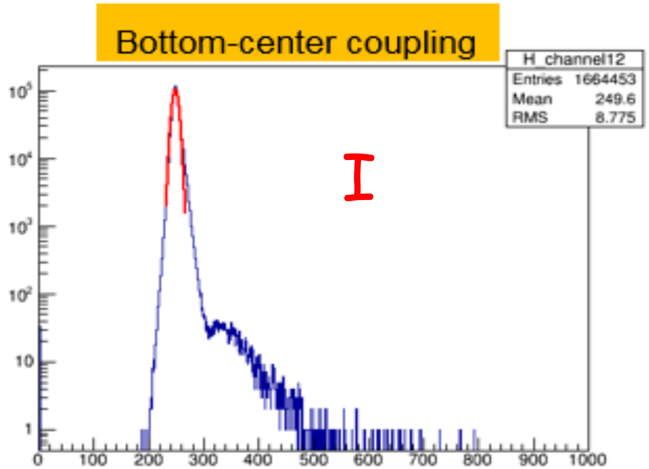


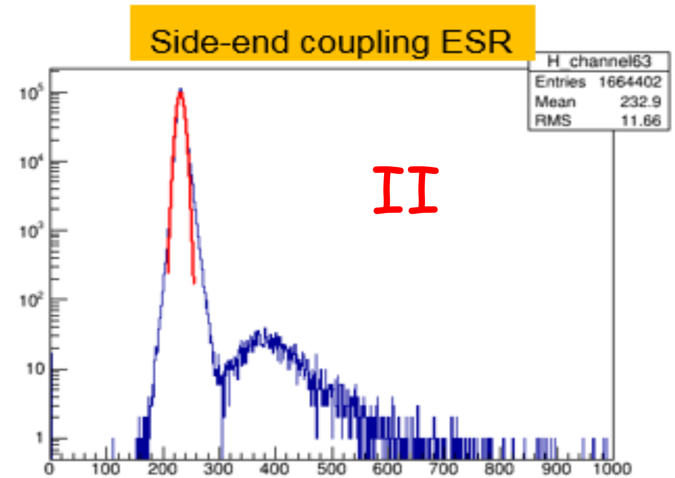


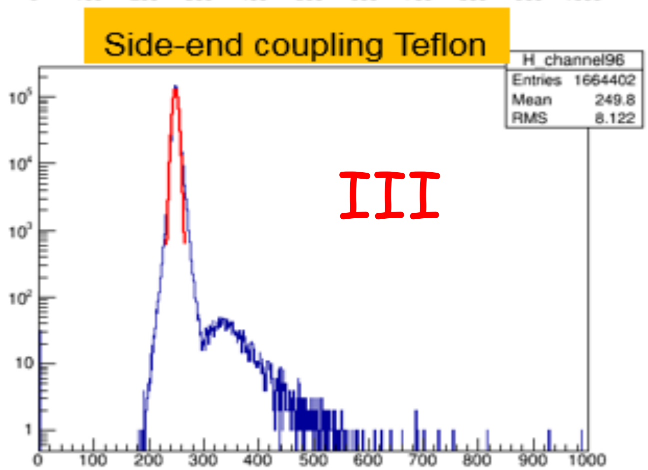


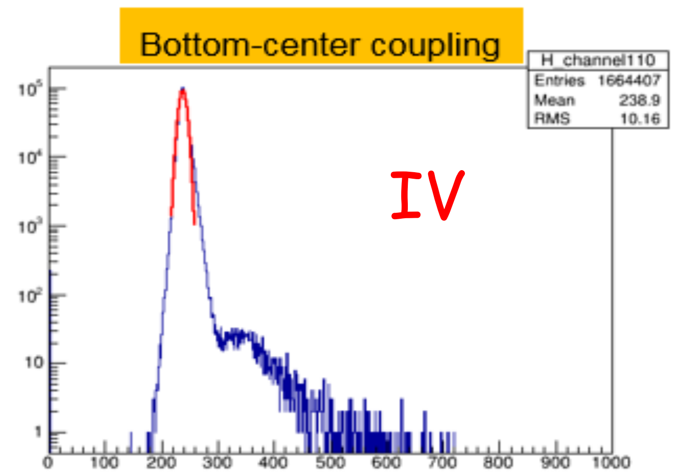


Single Layer Prototype









Summary

- The Sci-W PFA ECAL was studied in two groups
  - Shinshu University
  - CEPC ECalorimeter group
- The types of sensitive elements were fixed, but still could be updated in future if some new photosensor and electronics chip update.
- Prototype of ECAL will be built this year and beam test will be started next year.

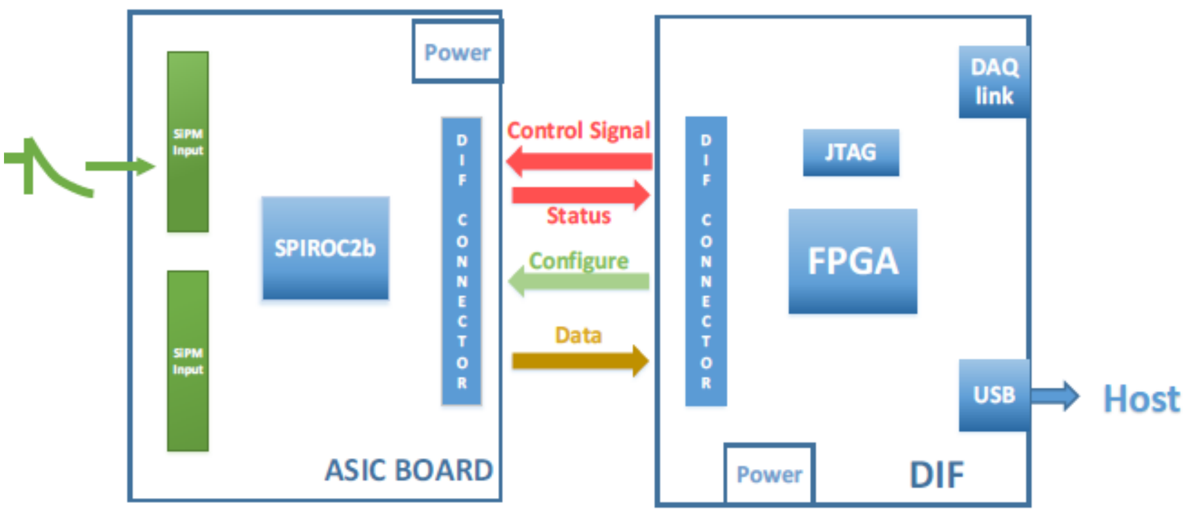
Thanks

Backup

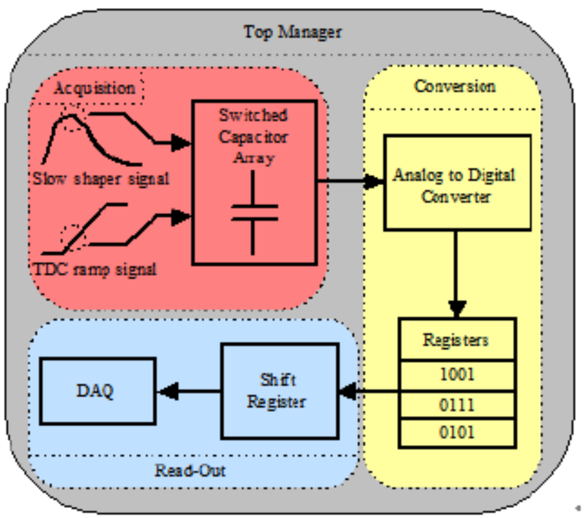
Readout Electronics

- SiPM front-end with **ASIC SPIROC2b/SPIROC2e** of 36 channels
- **FPGA** (Artix-7 200T)
- DIF is **compatible for further FEB**
- USB for data upload & cmd sending
- USB for single DIF, and **serial port for DAQ** when using multiple DIF

- Switched capacitor array store charge measurement
- 12 bits ADC conversion
- Variable Gain due to:
    - adjustable C_f of pre-amplifer
    - R_{load} on the board
    - Shaping time and delay



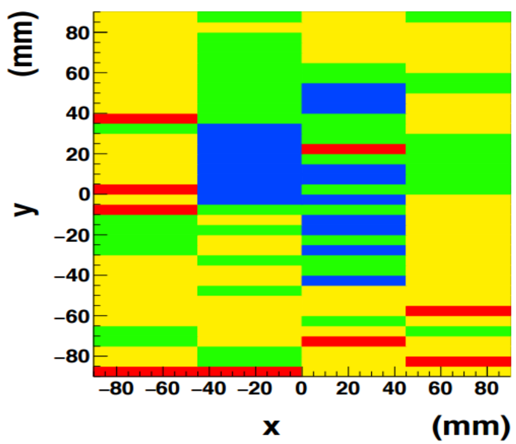
System schematic



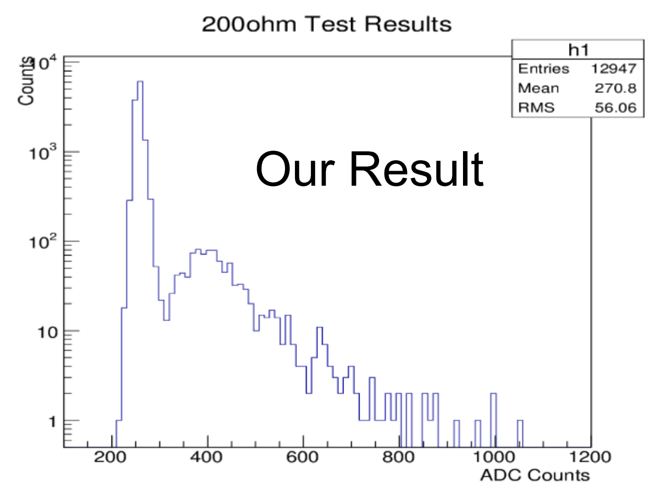
ASIC High level diagram

Test Results

- Compared with CALICE-EBU ECAL

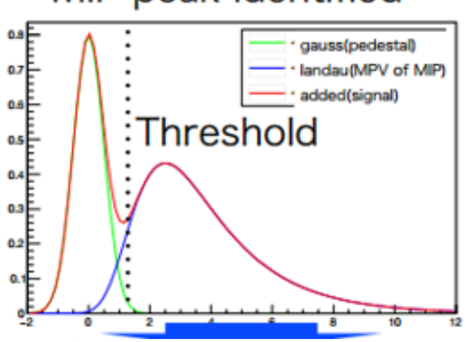


- MIP peak identified
  - 18 ch (12.5%)
- Shoulder found
  - 45 ch (31.25%)
- Tale only
  - 72 ch (50.00%)
- Dead or noisy channel
  - 9 ch (6.25%)

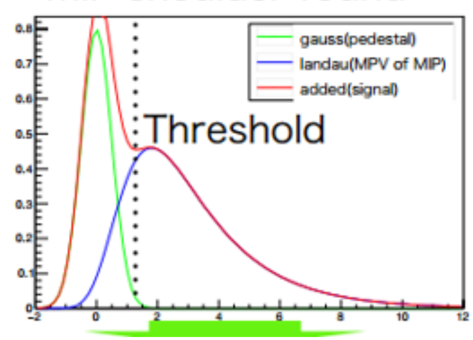


- Peak identified channels are only 12.5%.
  MIP peak identification with 10k pixel MPPC is not easy.

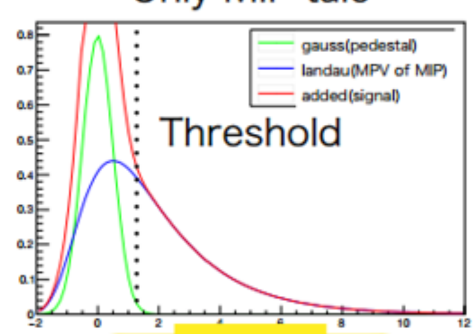
MIP peak identified



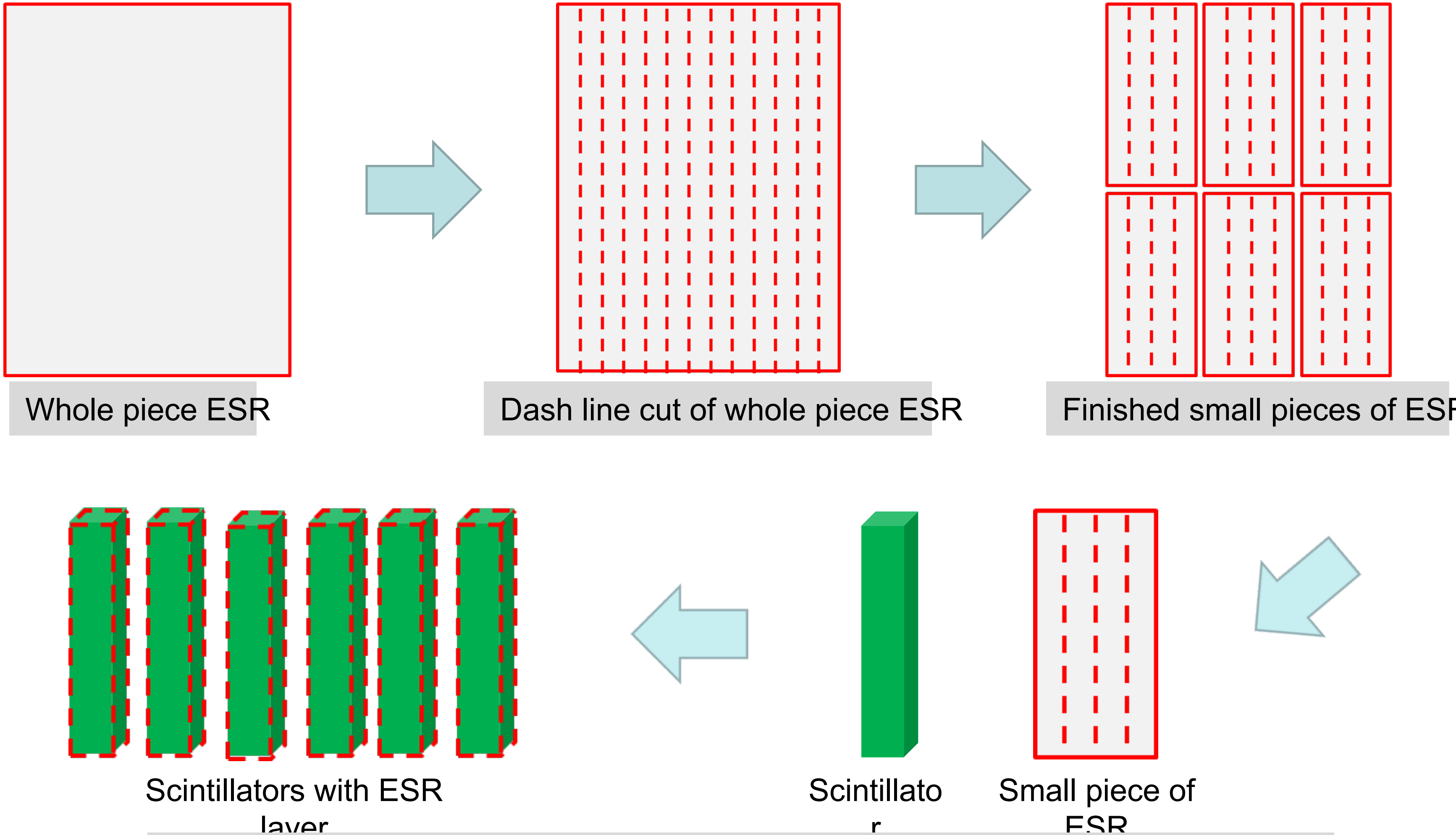
MIP shoulder found



Only MIP tale



CALICE-EBU ECAL Results



A schematic showing the cutting of ESR and assembling of scintillators

- ESR反射层的规模化分割技术非常成熟，产能和效率非常高，无技术瓶颈

Calorimeter

ECAL Barrel Inner radius R1 = 1.8m, Outer radius R2 = 2m, length L= 4.7m,
Nlayers=30 Area of Barrel = 2*PI*[(R1+R2)/2]*L * NLayer = 1687 m2 ~ 1700m2

ECAL Endcap Inner radius r1 = 0.35m, Outer radius r2 =2m,
Nlayers=30 Area of Endcap = 2*PI*(r2*r2 - r1*r1) * NLayer = 730 m2

总面积 1700 + 730 = 2430 m2， 总通道数：1.1*10^7

前端板，7mW/channel * 1.1*10^7channel = 77kW

数据接口板，主要是FPGA功耗大，另外如果采用光纤传输模式（另一个大功耗模块），加起来DIF板功耗可以接近4W，如果再考虑SiPM电源模块，可以把功耗适当放宽至在5W，假设一个DIF板负责1个平方米的区域，这样DIF总功耗为 2430m2*5W/m2=12.15kW

总功耗为 77 + 12.15 ≈ 90kW