The Development and Performance of Sci-W ECAL Prototype of CEPC

Yunlong Zhang

State Key Laboratory of Particle Detection and Electronics, China

University of Science and Technology of China

On behalf of CEPC Calorimeter working group

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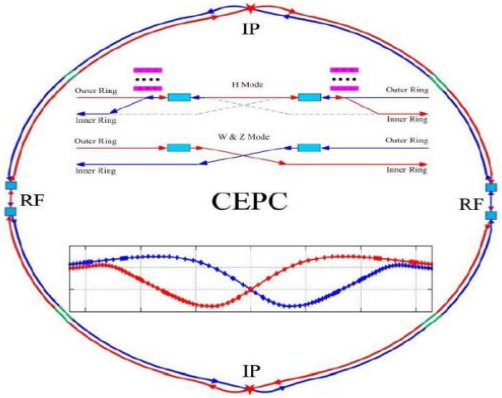
Outline

- Motivation
- Scintillator-Tungsten ECAL
  - Sci-W ECAL Development
  - The Performance of ECAL
- Summary

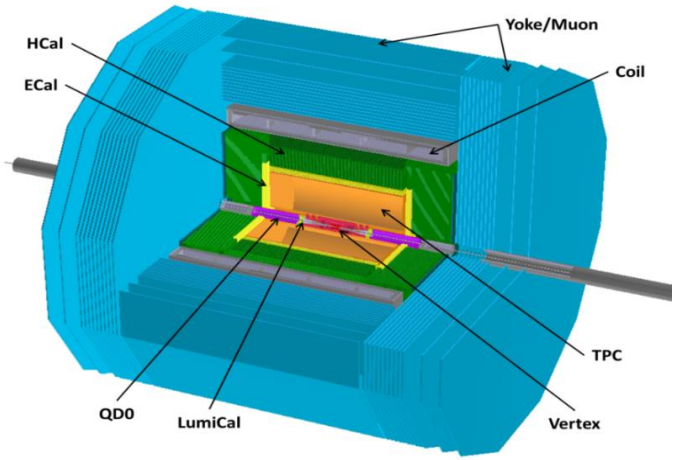
Motivation

- **Circular Electron Positron Collider (CEPC)**
  - E_{cm}≈240GeV, 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)



Challenges:

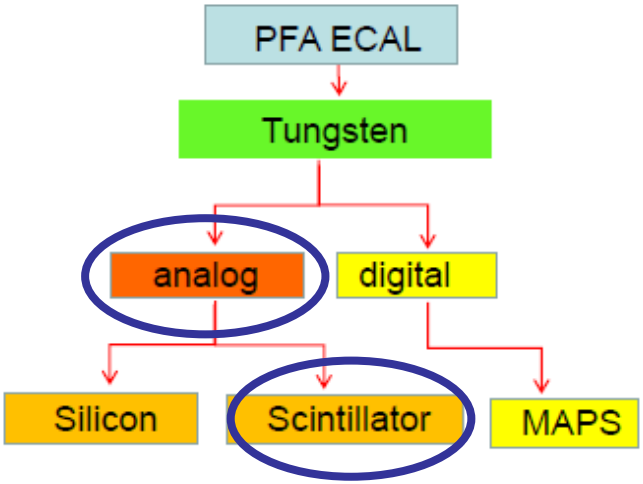
- **Momentum:** $\sigma_{1/p} < 5\times10^{-5}\ \mathrm{GeV}^{-1}$
- **Impact parameter:** $\sigma_{r\phi} = 5 \oplus 10/(p\cdot\sin^{\frac{3}{2}}\theta)\ \mu\mathrm{m}$
- **Jet energy:** $\frac{\sigma_E}{E} \approx 3-4\%$

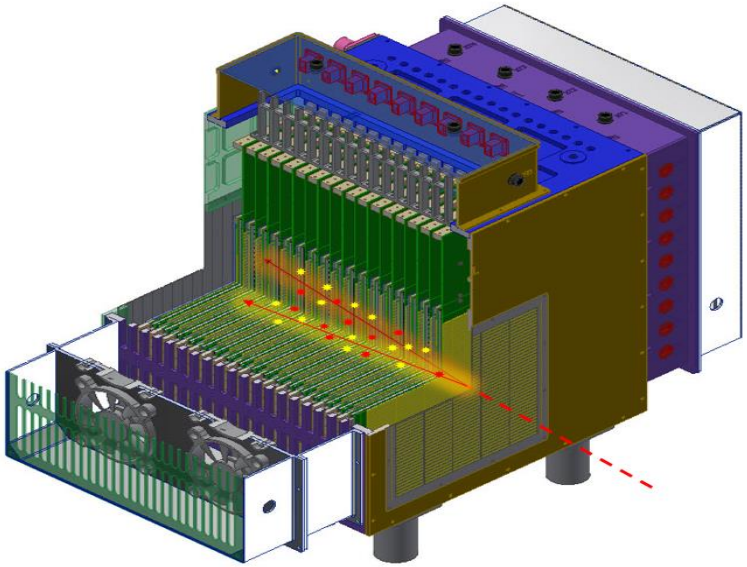


- The Particle Flow Algorithm (PFA) calorimeter concept was proposed
  - High granularity
  - Good track finding
  - Good energy resolution

Sci-W ECAL Prototype

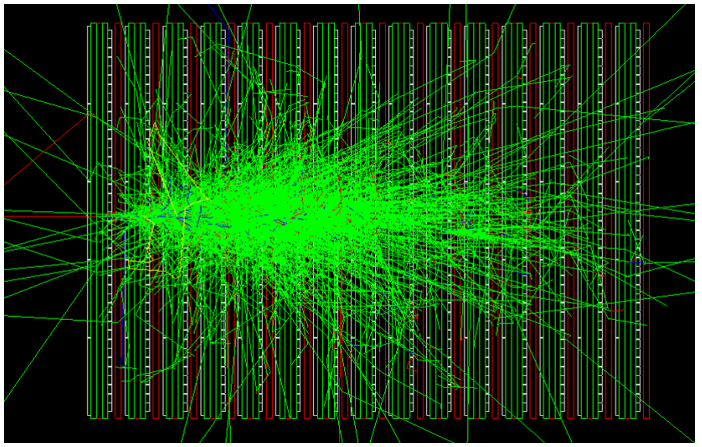
- Sampling Calorimeter
  - Sandwich structure
  - Absorber + Sensitive Detector
    - Tungsten+Copper (85%:15%)
    - Scintillator + SiPM
- It has 30 single layers
  - Each layer has 210 channels
  - The thickness of absorber is 3.2 mm, ~0.73 r.l
  - 22 r.l
- two layers are orthogonal to form a super layer

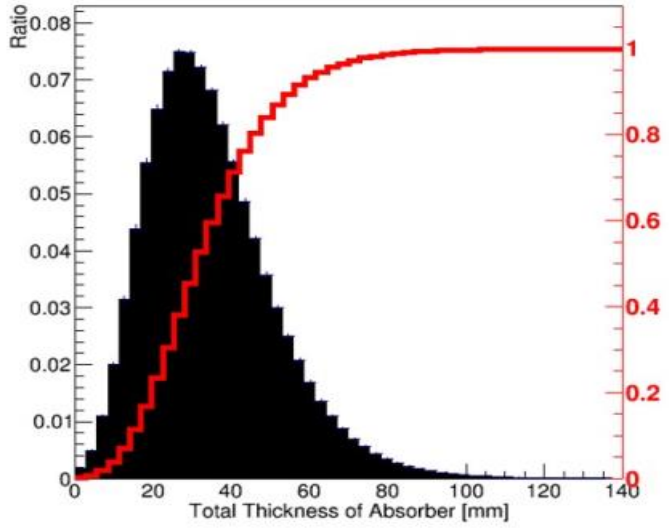


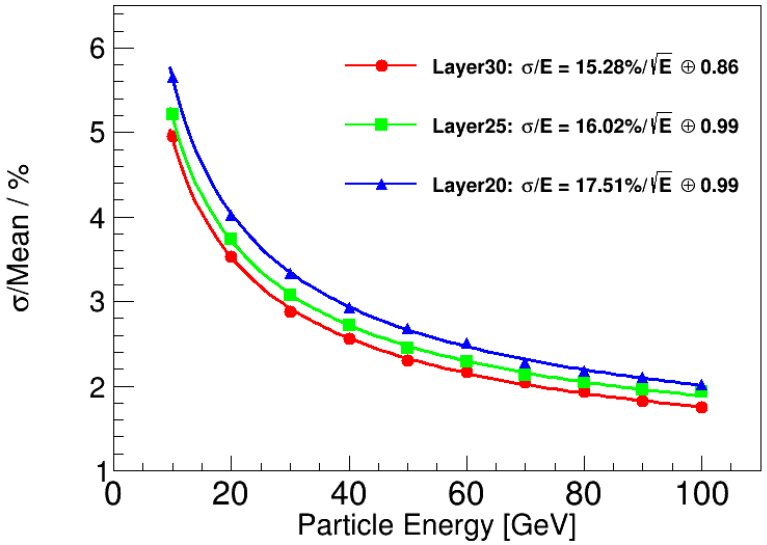


Sci-W ECAL Prototype

- Based on Geant4 simulation
  - The energy linearity is good
  - The energy resolution could be better than 16% @ 1GeV



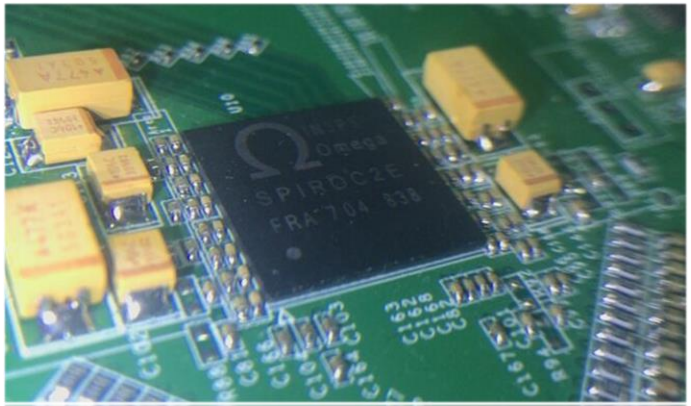




Elements of ECAL

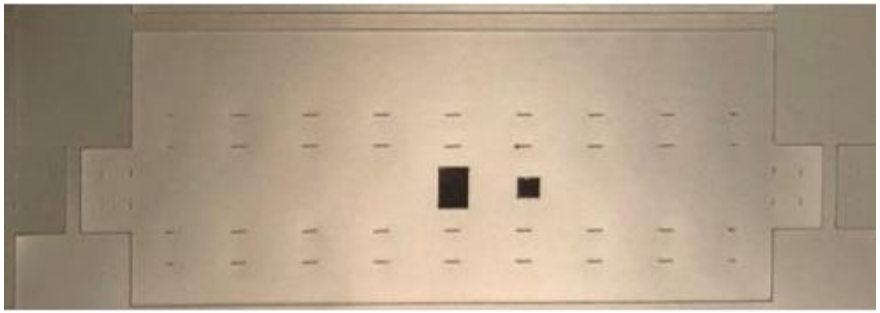
Scintillator （5mm*45mm*2mm）

SiPM（1mm＊1mm）

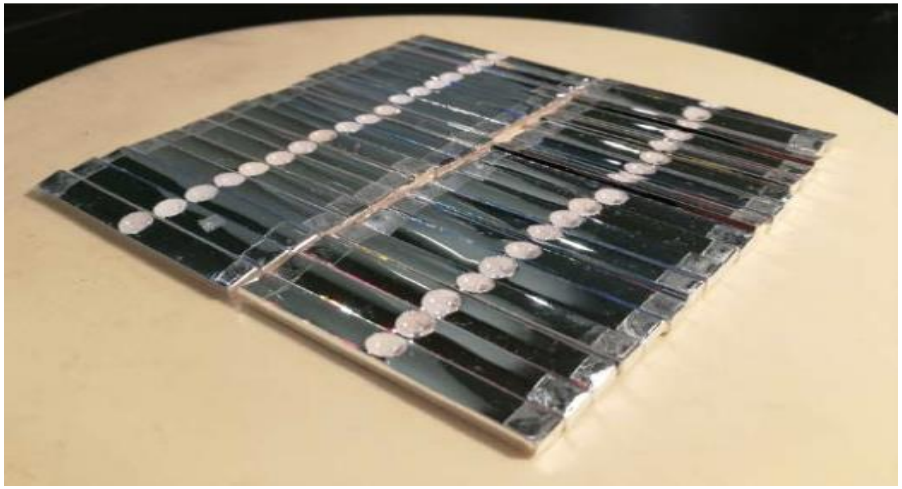


- Dynamic range：~100fC~200pC
- channels：36
- Polar: positive
- power：8 mW/channel
- Memory cell: 16

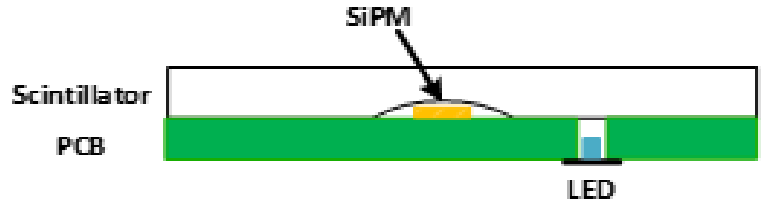
Scintillator

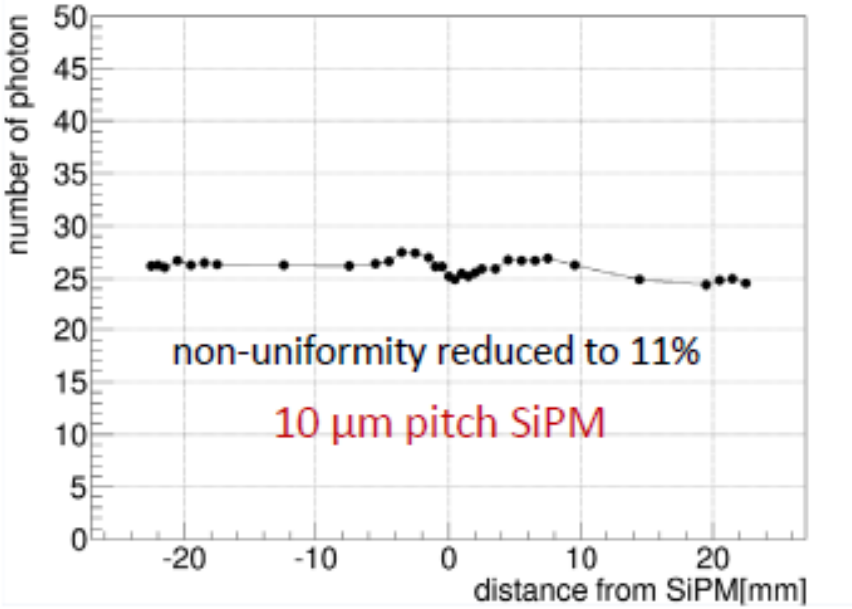


ESR film



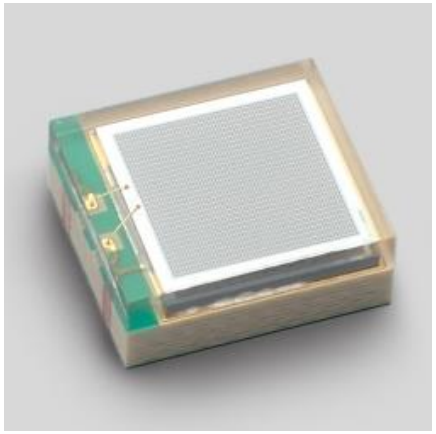
Scintillator

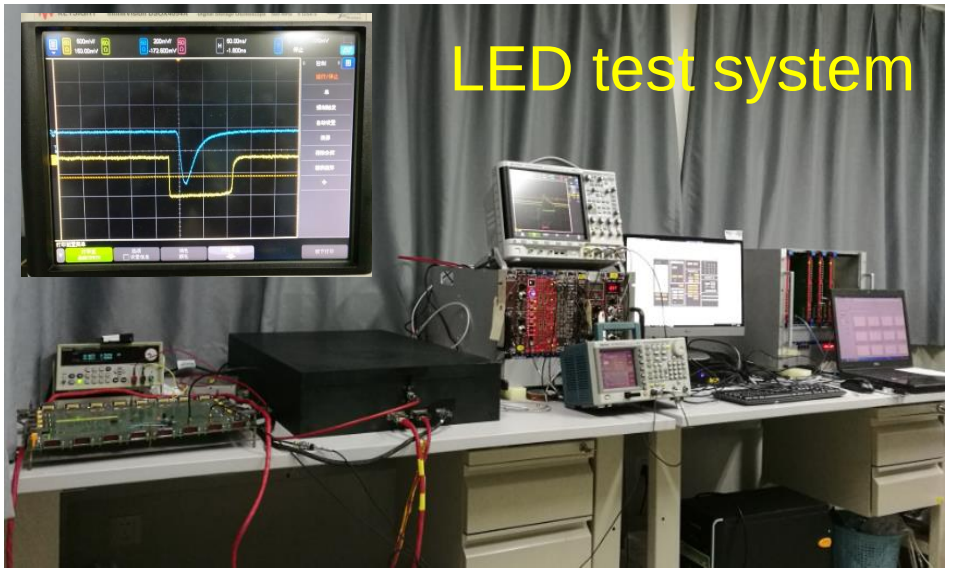




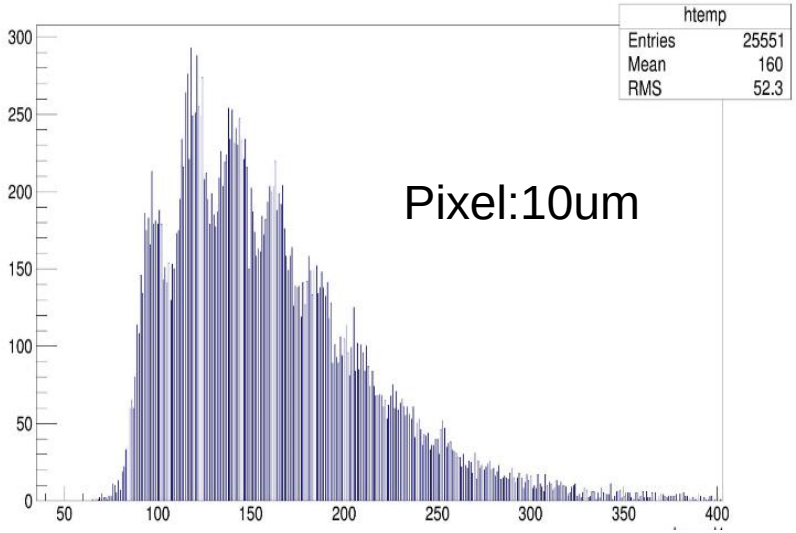
The light collection uniformity

SiPM



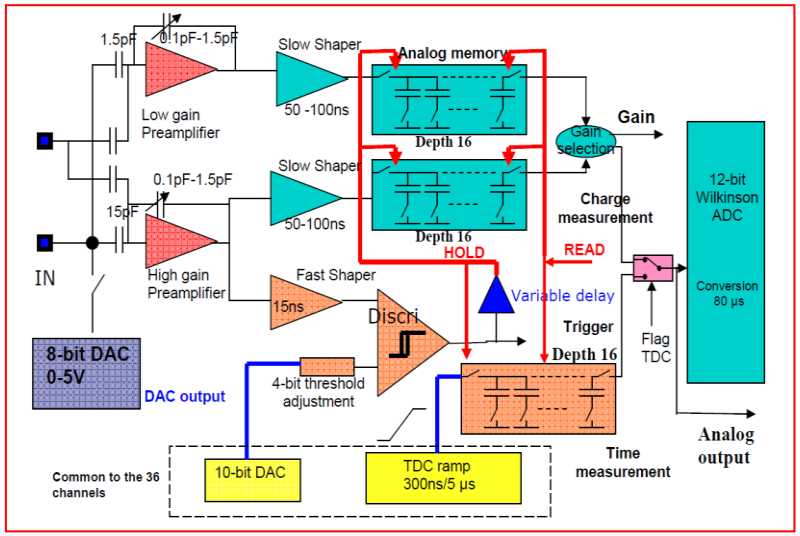


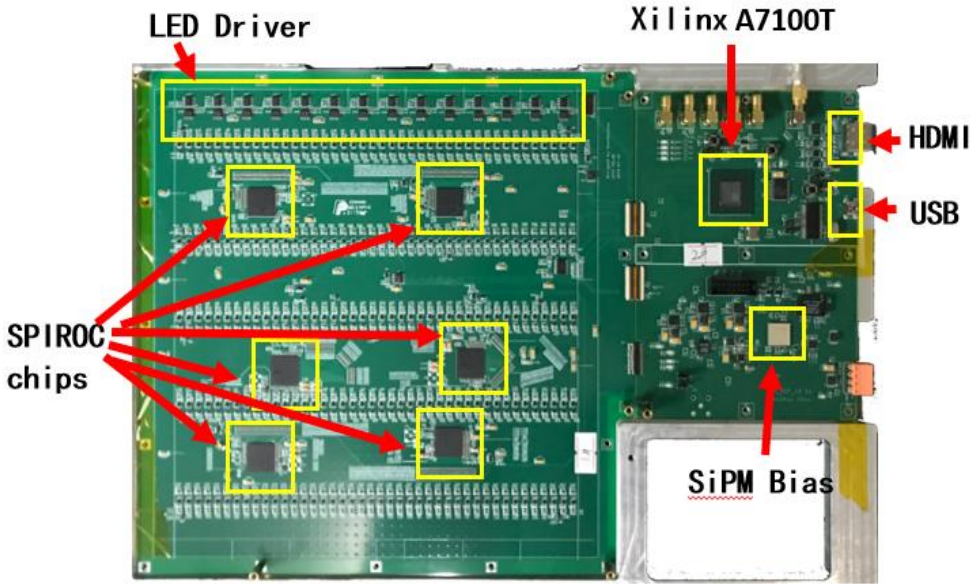
Type	S12571-010P	S12571-015P
Pixel size	10um	15um
Gain	$1.3x10^5$	$2.3x10^5$
PDE	10%	25%
Capacity	35pF	35pF
Temp.Coeff	1.2%/℃	1.5%/℃
V_{op}	70±10	69±10



Electronics design based on SPIROC2E

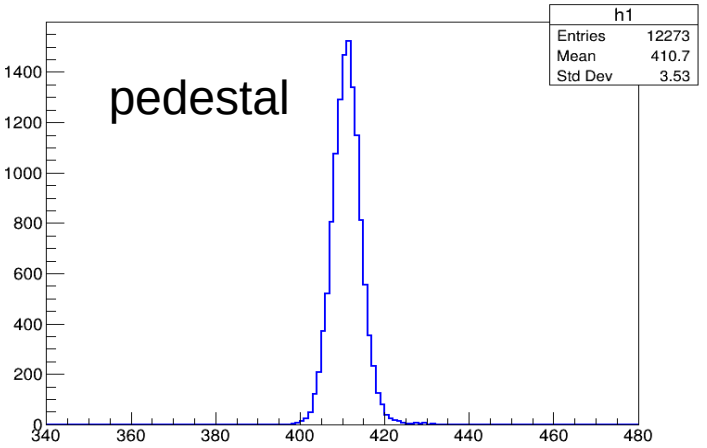
- The electronics board has 6 SPIROC2E chips
- It has three main additional functions
  - DAC calibration
  - LED Test for SiPM
  - Temperature Monitor

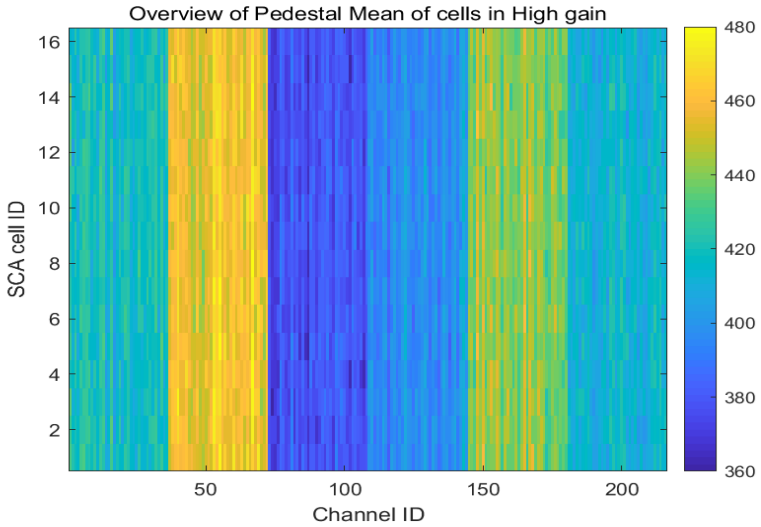




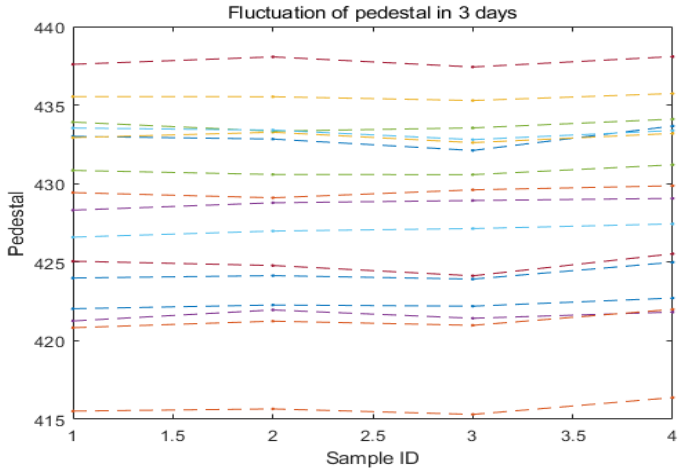
Noise Test

- Pedestal position represents the offset of amplitude
- Pedestal width means noise level
- Different channels of the same chip have good consistency





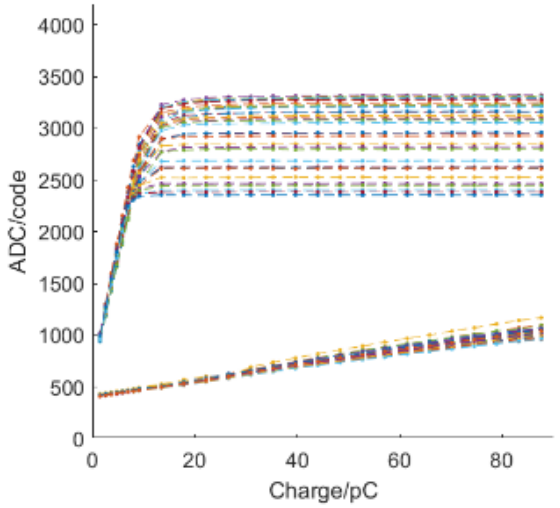
Pedestal of each channel



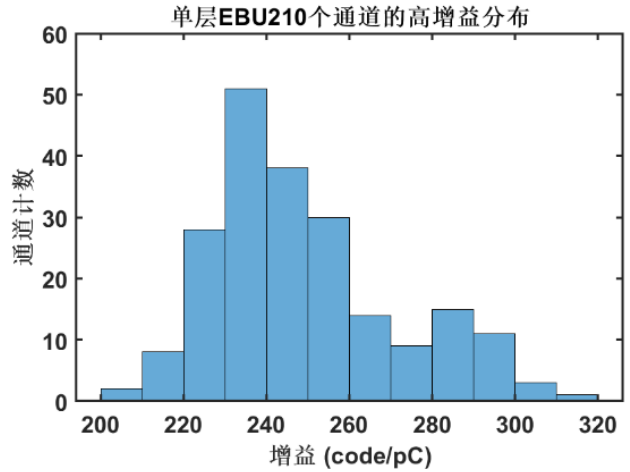
Pedestal position stability (3 days)

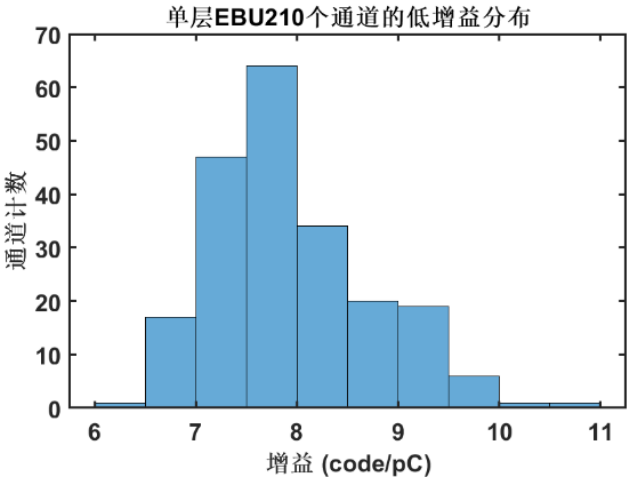
DAC Calibration

- DAC calibration could be used to test the sensitivity and linearity of each channel
- Dynamic range：
  - High gain channel 10 pC
  - Low gain channel 300 pC



Linearity of readout

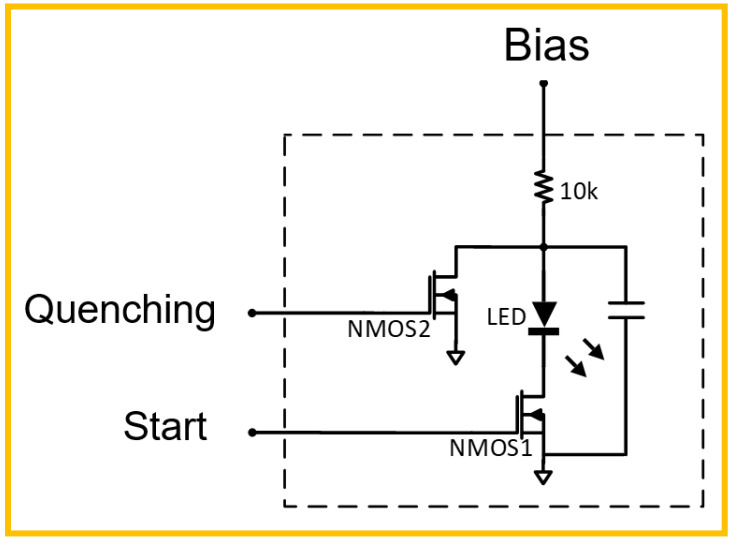


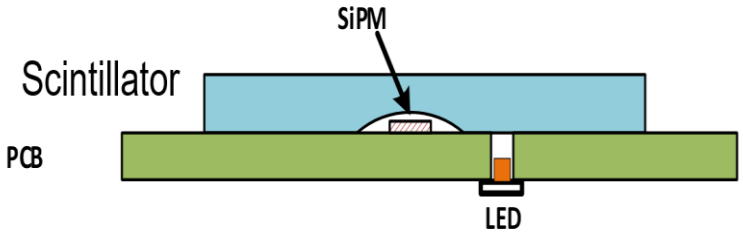


LED Test

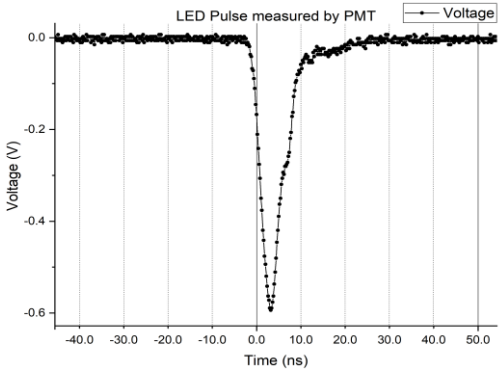
- A driving circuit is designed to test the LED
  - LED is placed near SiPM
  - The width of light pulse is similar to scintillator
  - The light intensity could be controlled by the circuit

drive circuit

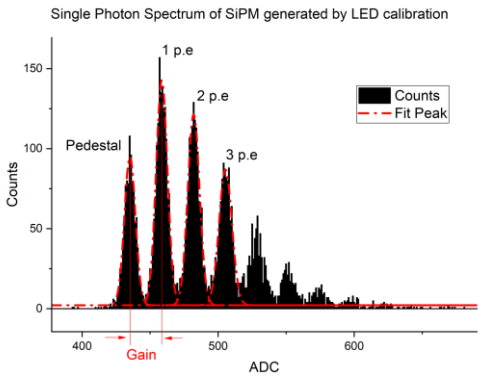




detector unit



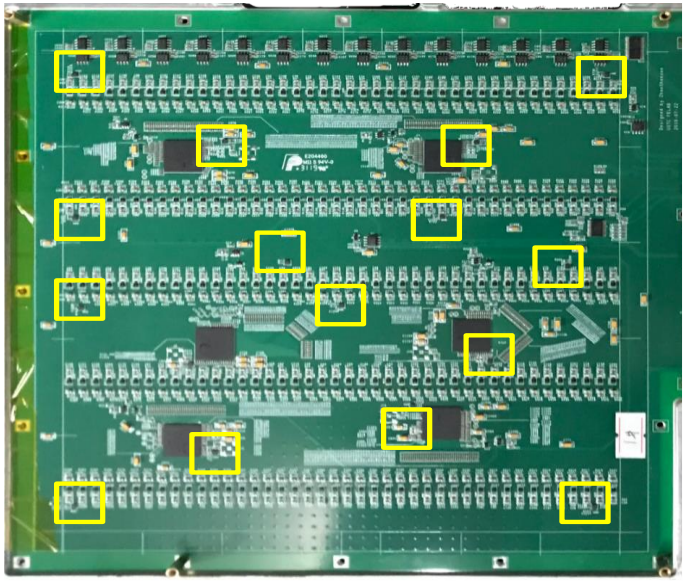
LED light



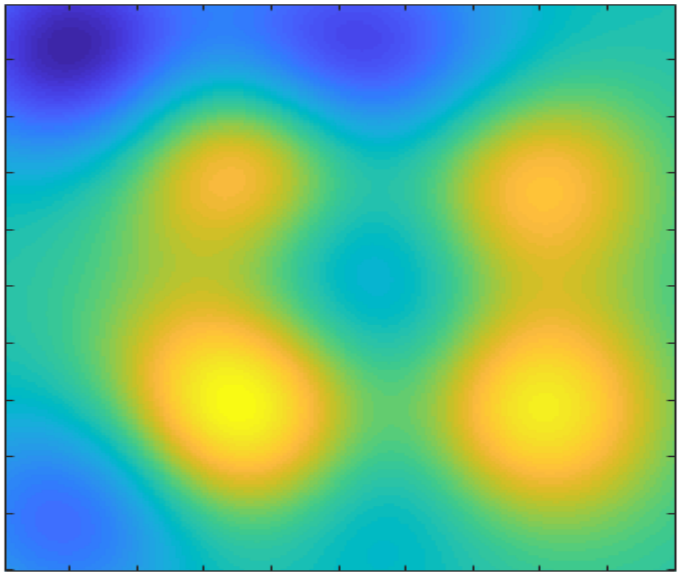
SiPM

Temperature Monitor and reconstruction

- 16 temperature sensors are placed on the electronics board
- The temperature information could be used to correct SiPM gain or other parameters



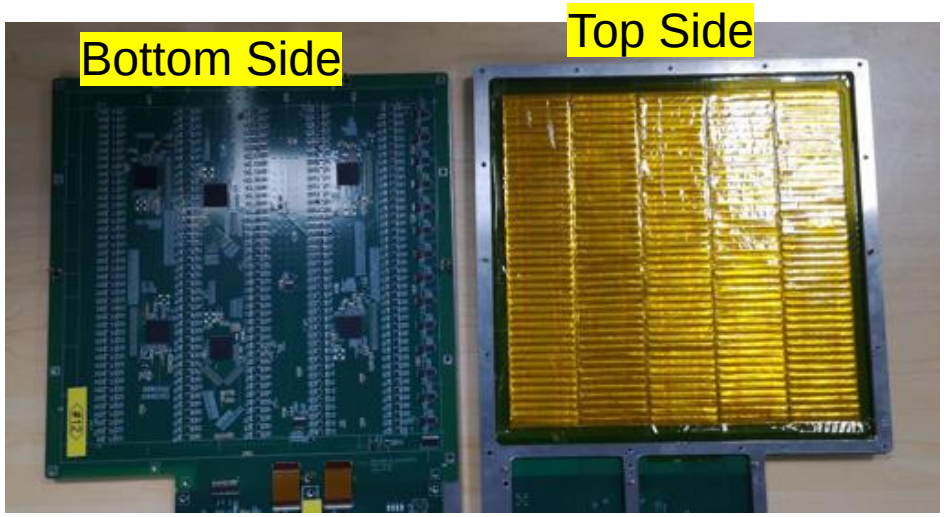
Temperature sensor



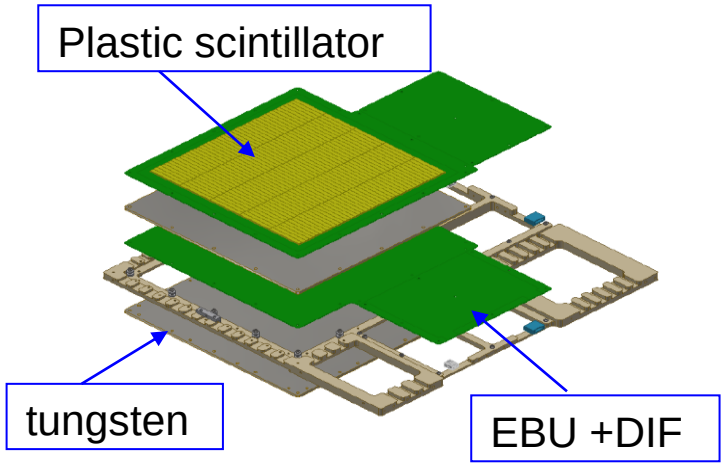
Temperature reconstruction

Sensitive Layer assembly

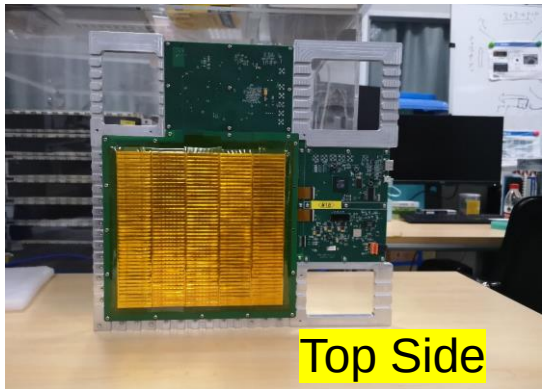
- Single layer (EBU)
  - Assemble the scintillator on the electronic board
- Superlayer
  - Two EBUs are assembled together to form a superlayer

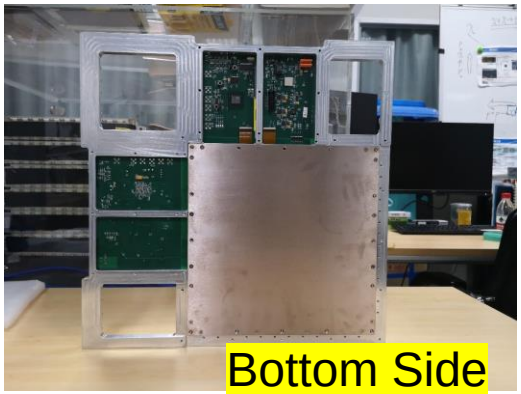


Single layer



superlayer

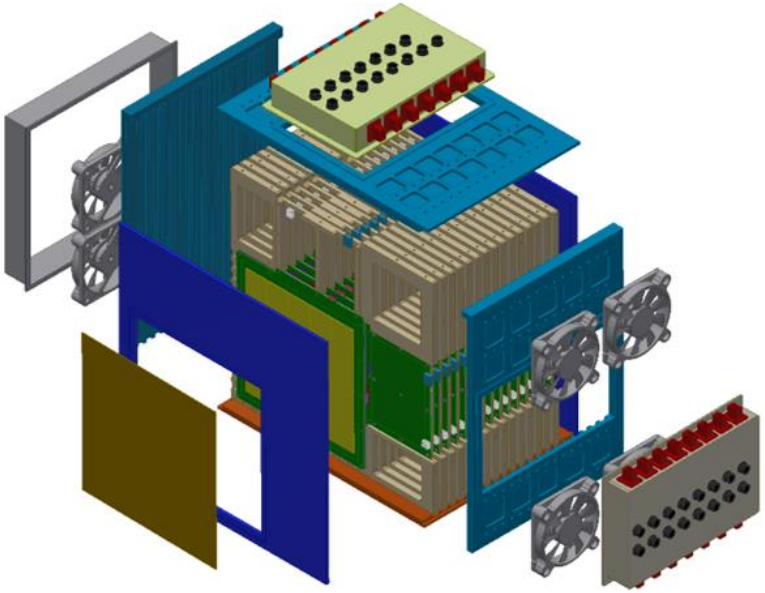


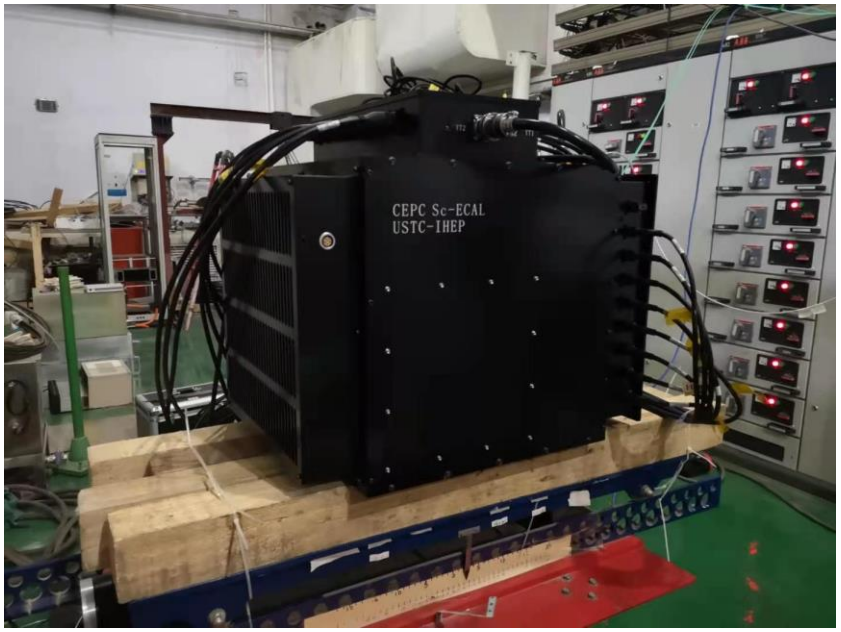


superlayer

Superlayer

Sci-W ECAL of CEPC

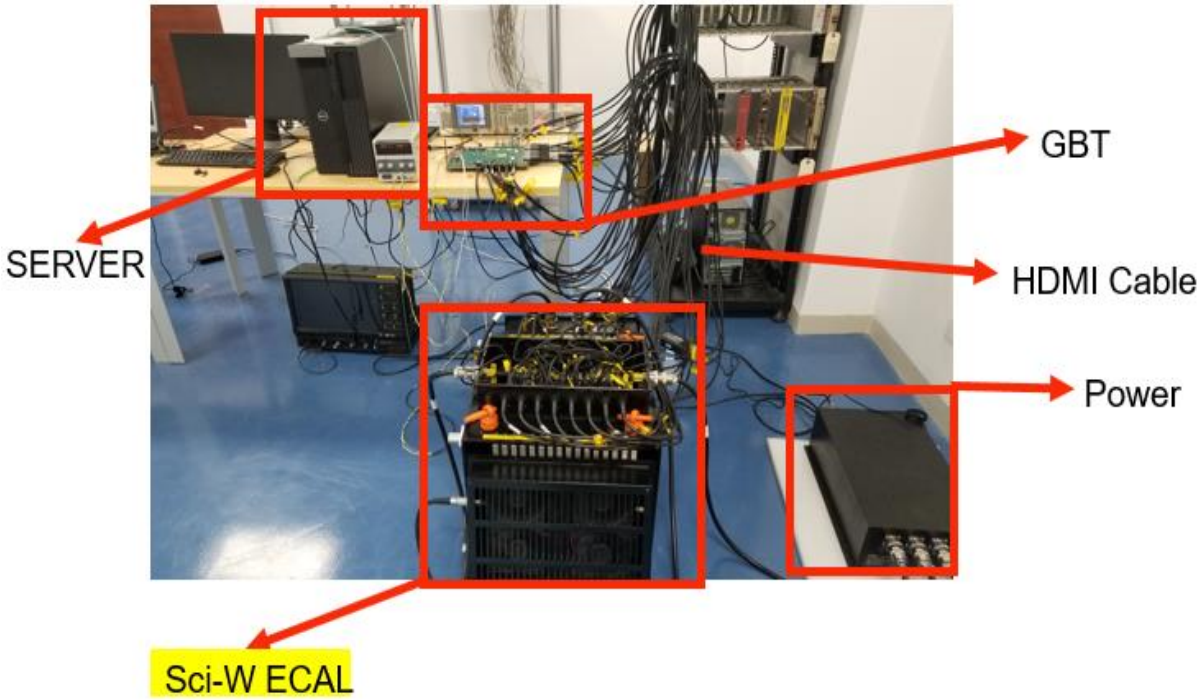




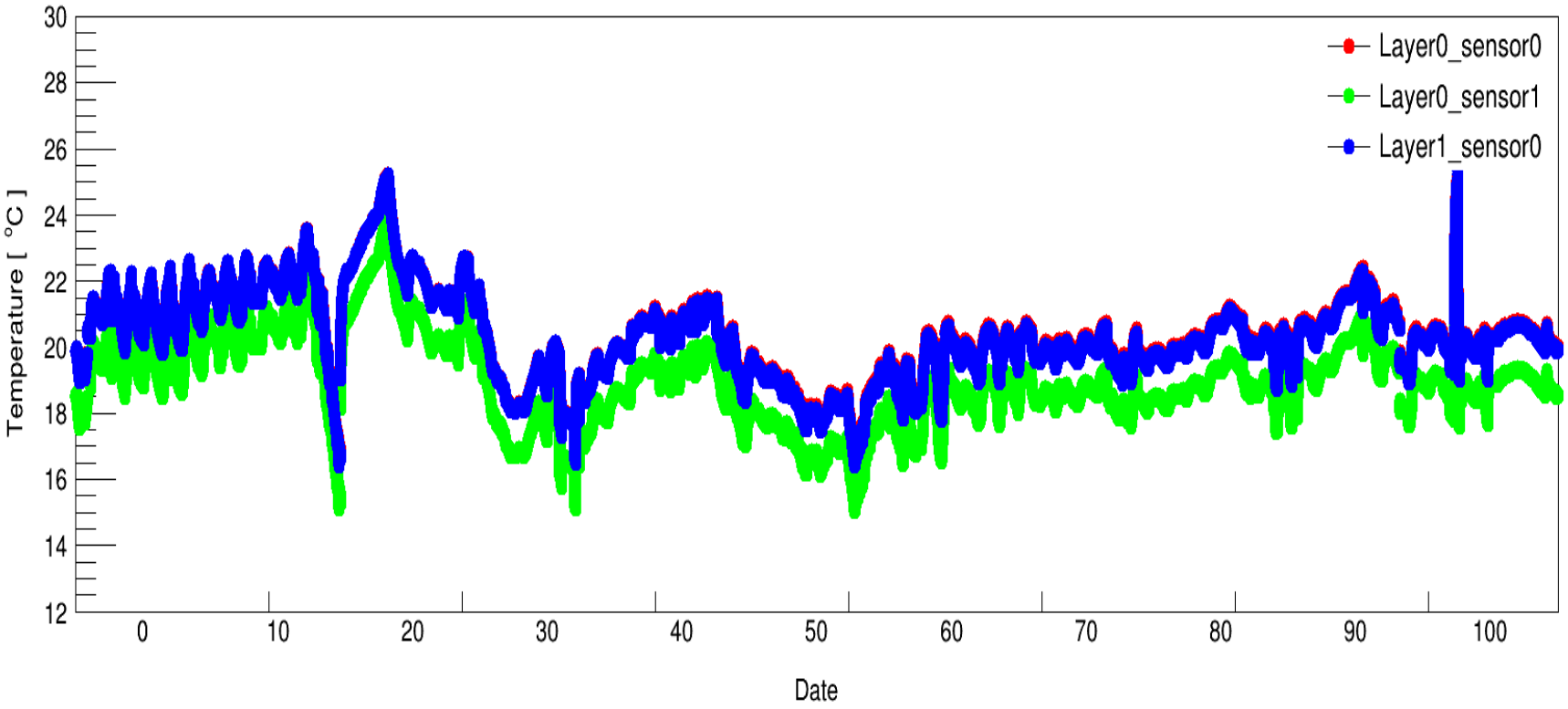
Cosmic Test

- Study the performance of calorimeter in long term, and some analysis methods also be tested with cosmic ray test
- Calibrate some important parameters of calorimeter, like the pedestal, low gain/high gain ratio, electronics linearity, energy scale and so on
- Also include the engineering parameters, like temperature, voltage, current..

- Long term cosmic ray test: ~100 DAYs
  - Coincidence trigger of Layer1 & Layer29
  - Event rate : ~ 16 per minute
  - ~1.5 million cosmic ray events collected



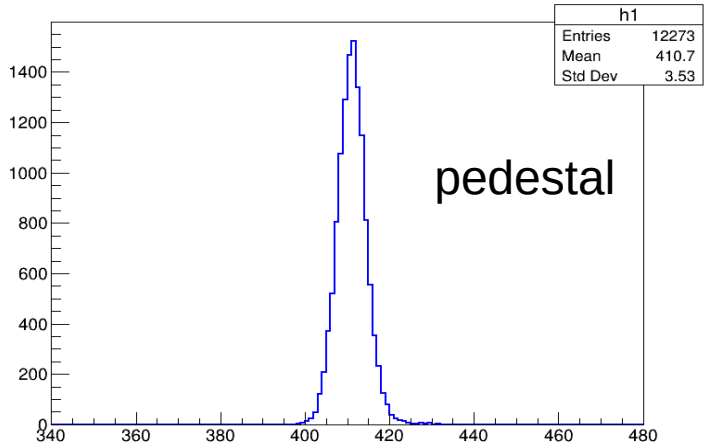
Temperature

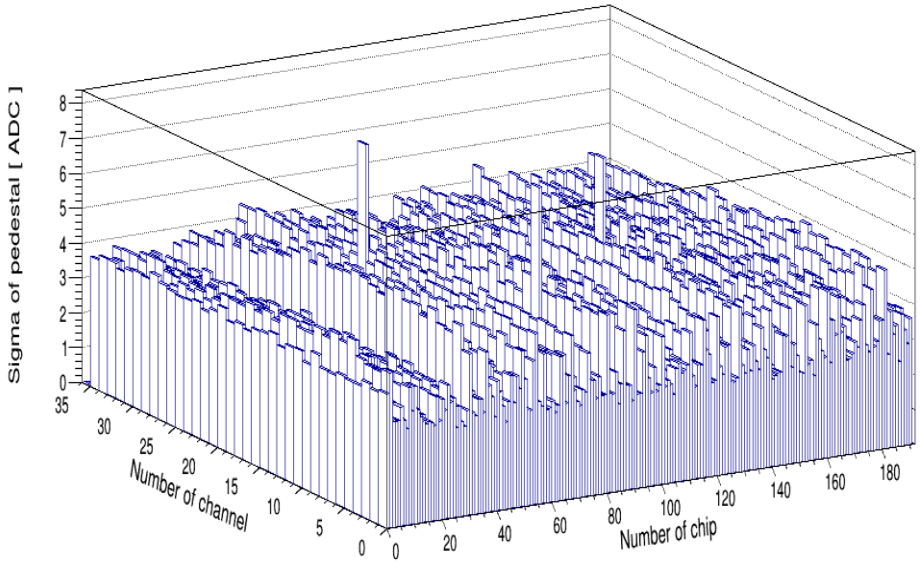


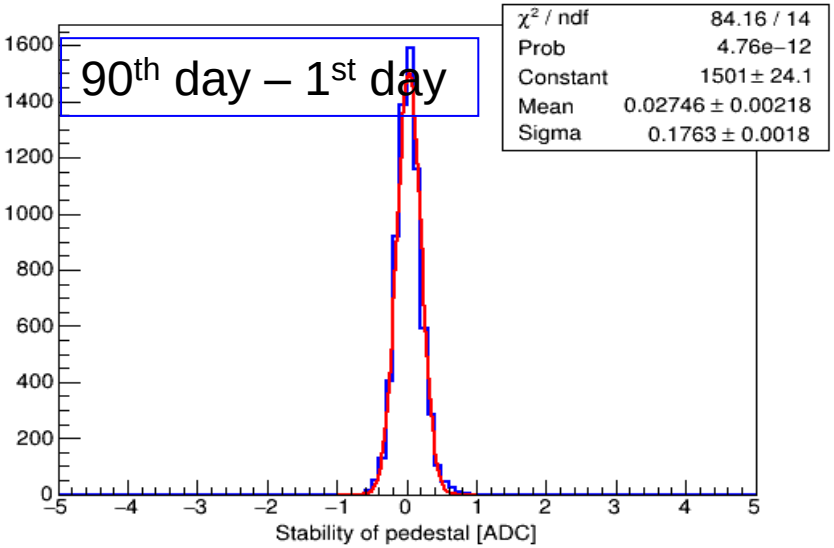
- The temperature is between 14 and 26 degrees, with an average of 20 degree
- There are slight differences in different locations in the same layer
- The temperature difference between different layers is also very small

Pedestal test

- The pedestal distribution could be get from “hittag=0” channel
- The pedestal width of 10 um and 15 um pixel SiPM are about 3-5 ADC counts



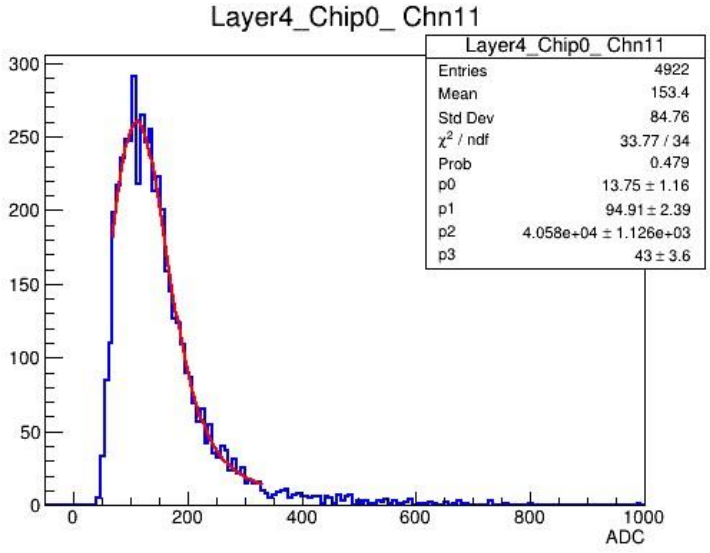




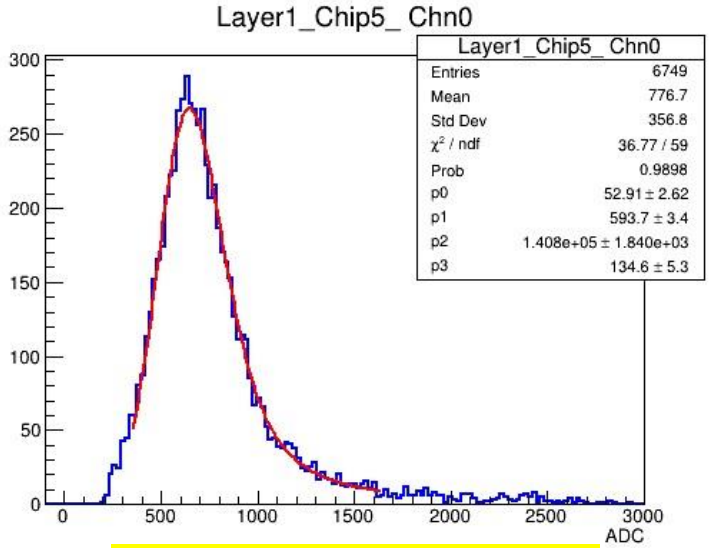
90-day shift, rms 0.2 ADC

MIPs

- In order to reconstruct the total energy deposition in calorimeter of incident event, we should know the deposition in each SD element
- MPV value of MIPs is the reference for energy reconstruction



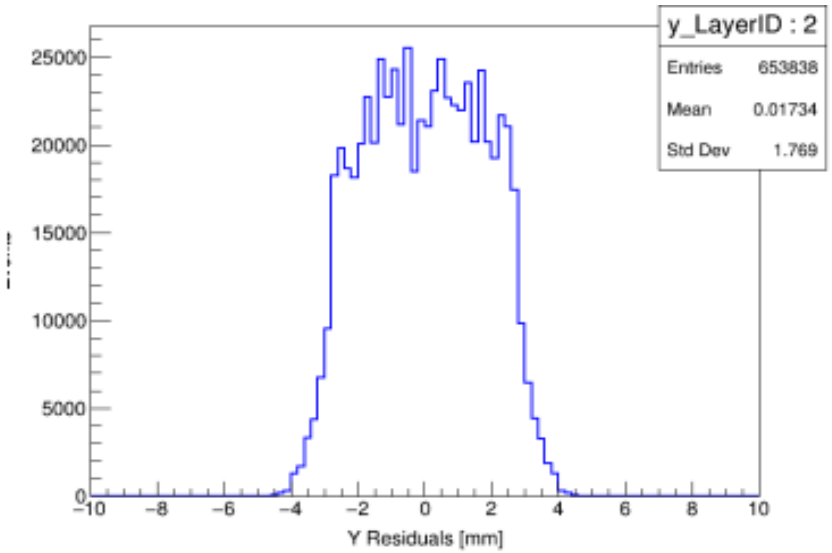
scintillator with 10 um SiPM



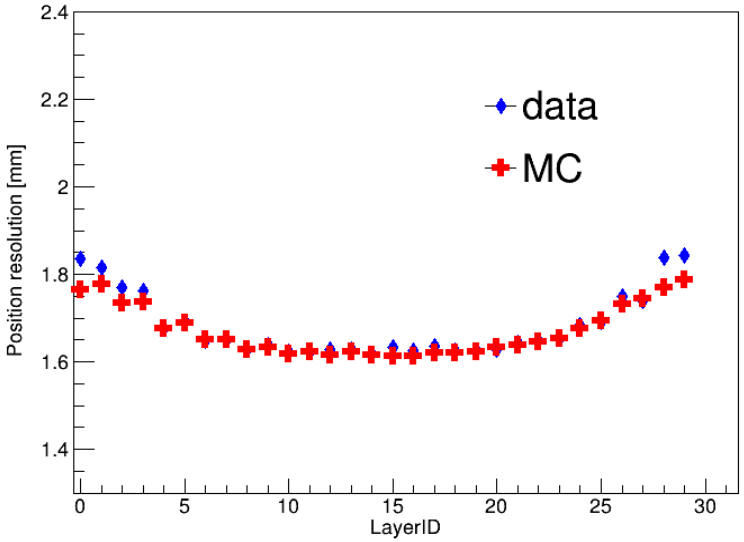
scintillator with 15 um SiPM

Position resolution

- Position resolution better than 2 mm
  - Strongly affected by large angle scattering
  - The RMS of residual distribution is referred as the position resolution
  - The settings of simulation should fine tuning



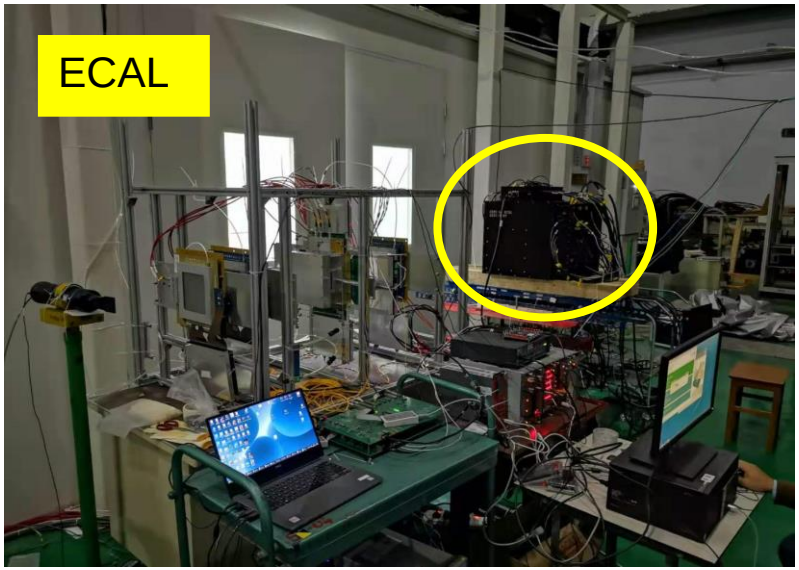
Position resolution along the 5 mm direction



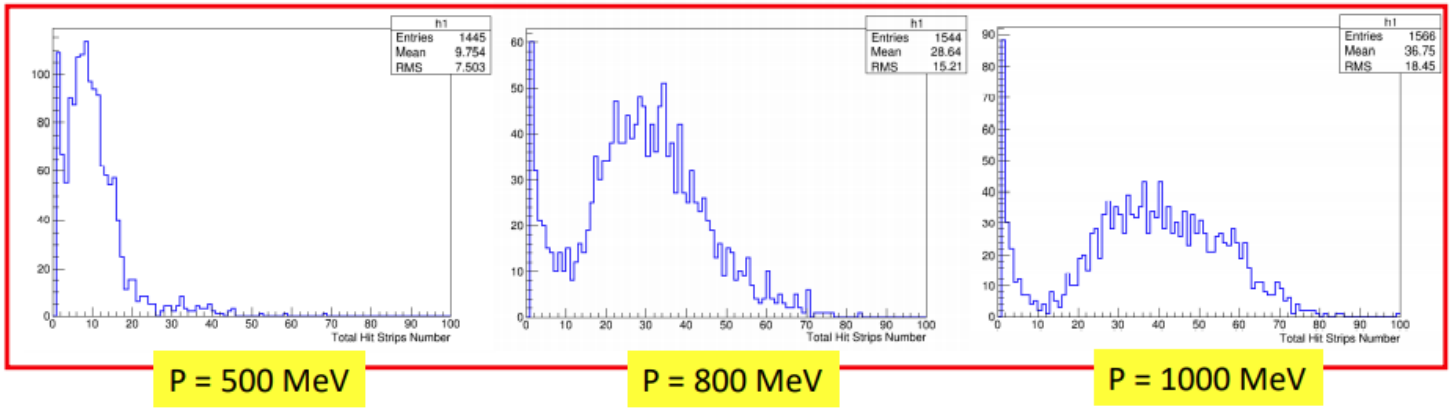
Resolution of each layer

Beam Test data reconstruction

- We carried out low energy beam test in IHEP
- Use the high energy electrons hit the target, select the secondary particles emitted at a large angle
  - Pion, proton..



E3 beam line in IHEP



Summary

- The Circular Electron Positron Collider (CEPC) is the next generation Higgs factory, which worked at $\sqrt{s} = 240GeV$
- A high granularity ECAL prototype for CEPC based on plastic scintillator is developed
  - It has 30 sampling layers and 6300 channels in total
  - The absorber is an alloy of tungsten-copper, and the total r.l is 22
- The long-term test based on cosmic ray shows that the prototype works well and all the main parameters are good.
- The test of low-energy particle beam is preliminarily carried out, and we hope that high-energy calibration can be carried out in CERN in future

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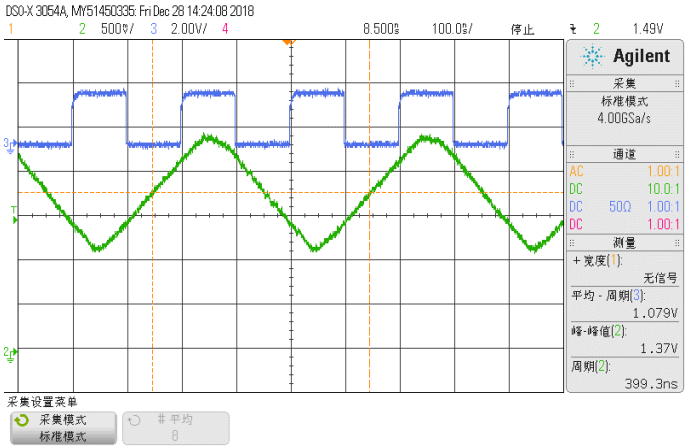
THANKS

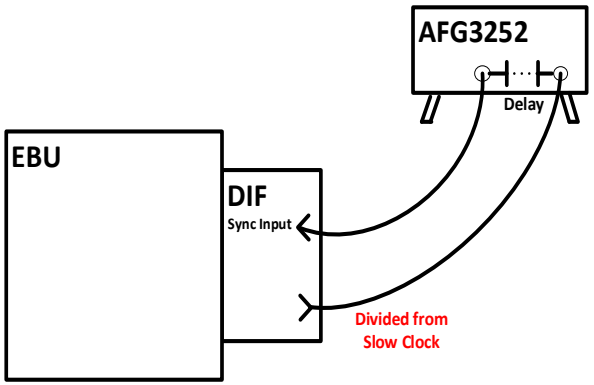
backup

Time Measurement

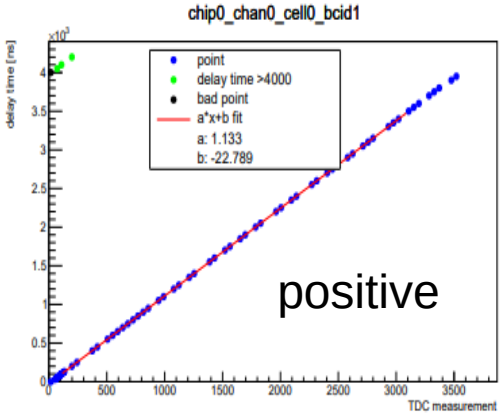
- Time response of SPIROC2E
  - SPIROC2E could give time information using an Integral TDC
  - two ramps: positive and negative
  - The linearity of TDC could be calibrated

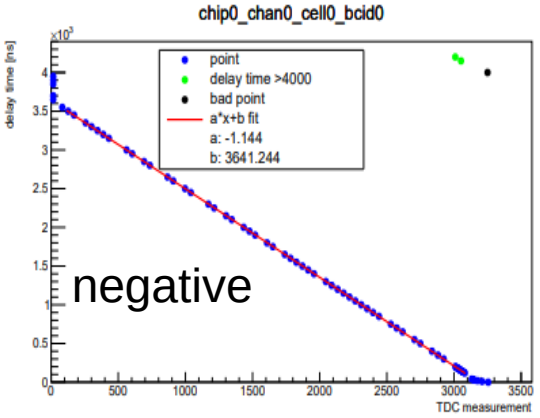


SPIROC2E chip



A pulse generator was used to calibrate the TDC

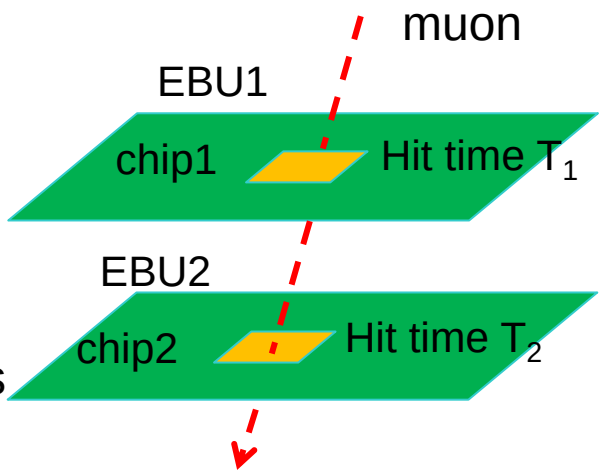


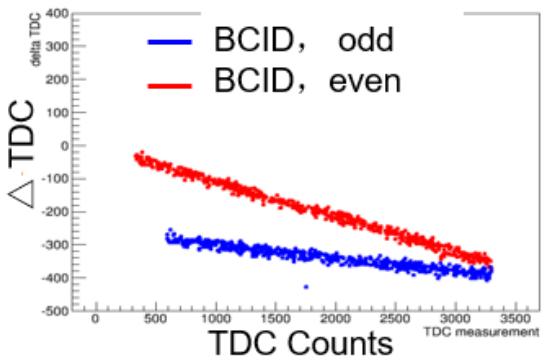


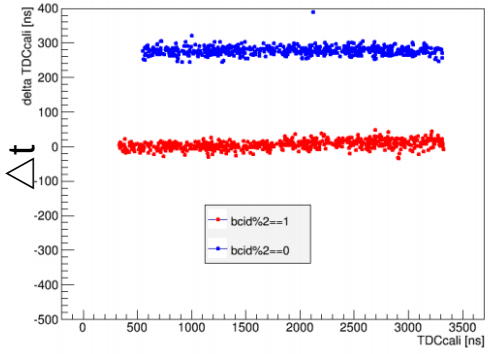
The linearity of TDC output

Time Measurement

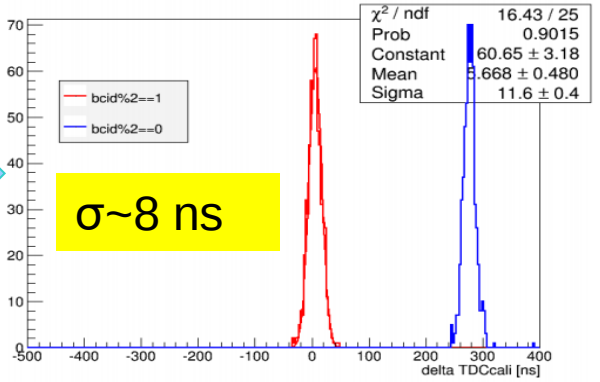
- Cosmic Ray could be used to calibrate the “TDC offset” of each chip or channel
  - Select one chip on each of the two EBUs
  - Calculate the difference of TDC channels measured by the two chips
  - The TDC counts to seconds convert coefficients are from pulse generator calibration





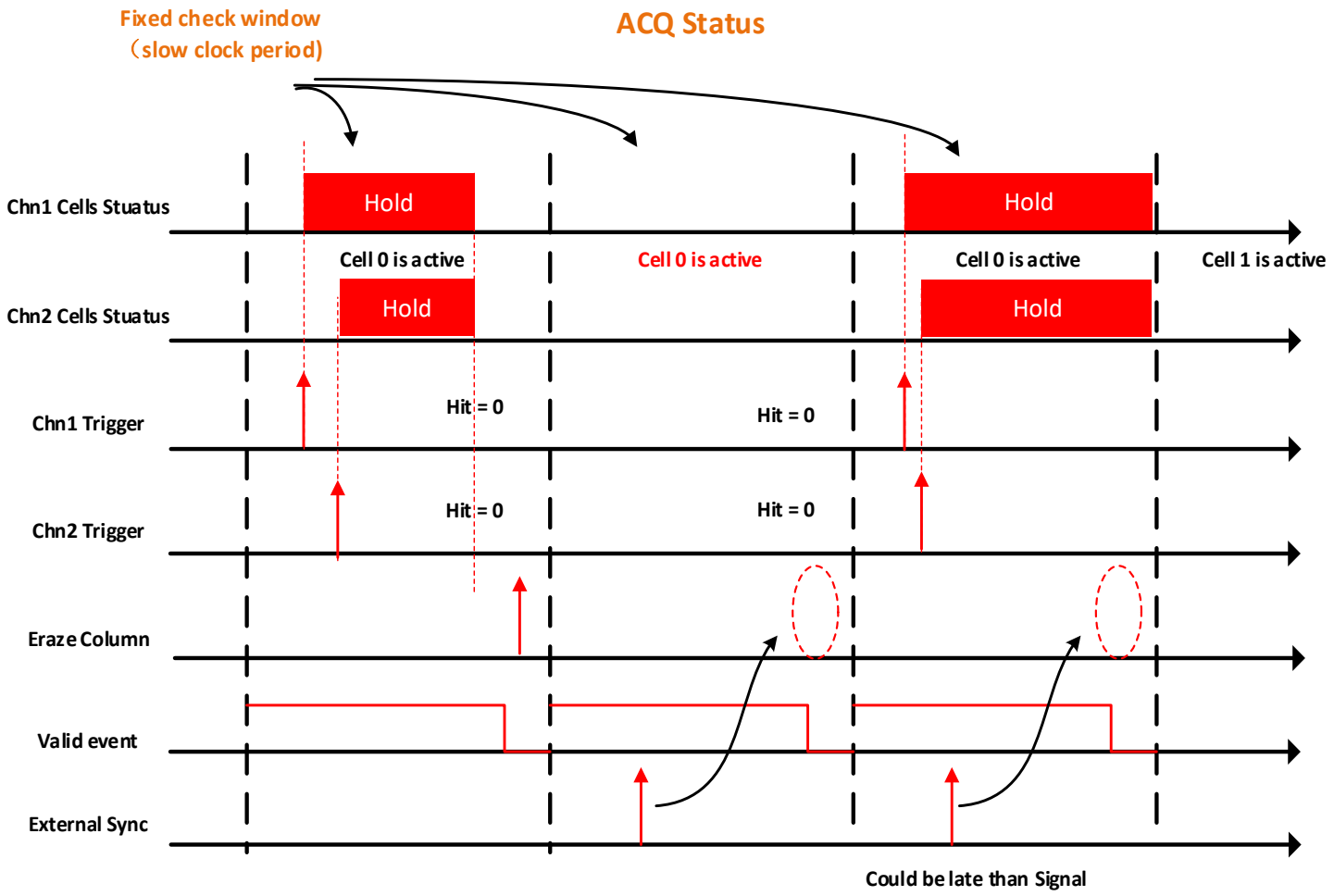


Time (ns)



Time resolution (ns)

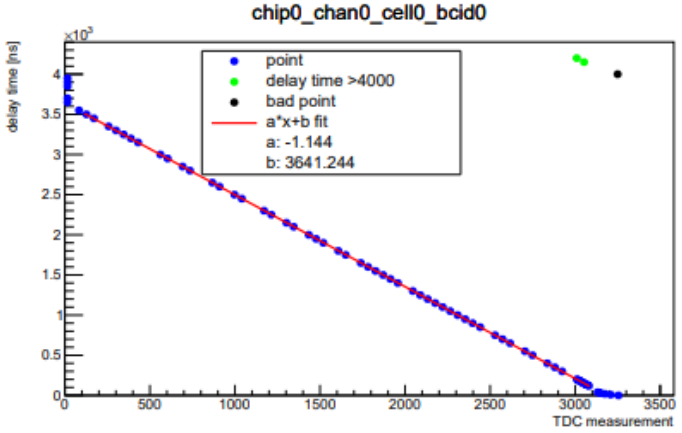
ECAL trigger

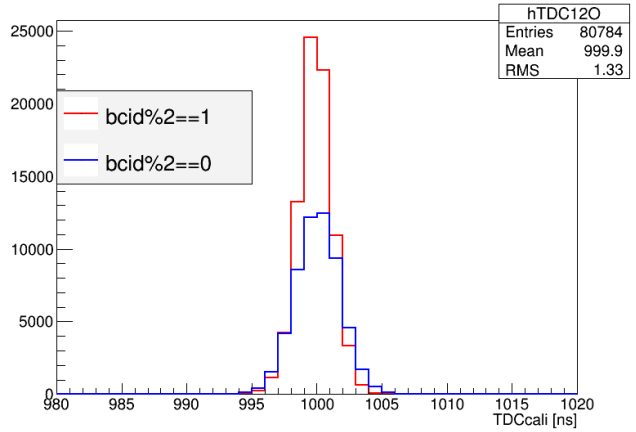


Validation Mode

Time calibration

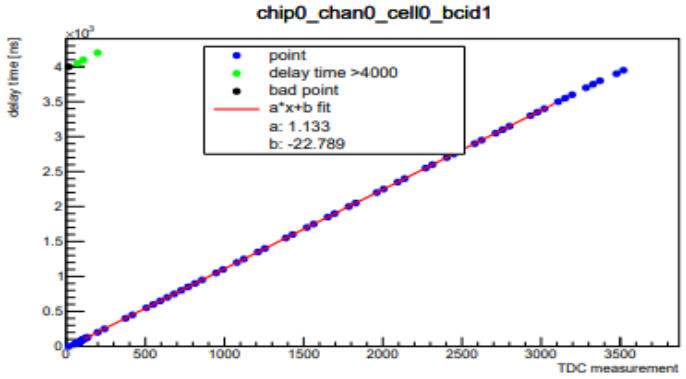
Negative slope ramp



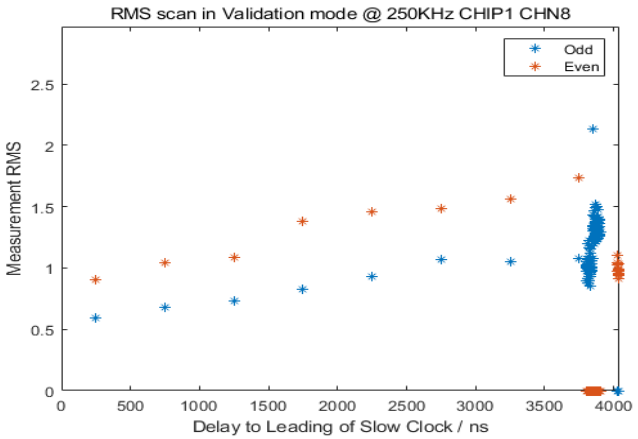


Time resolution at 1000 ns

Positive slope ramp



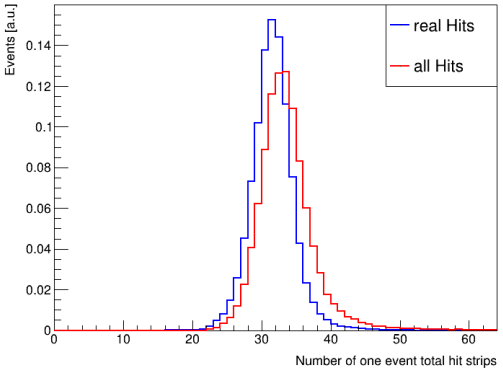
TDC Channel vs. delay time



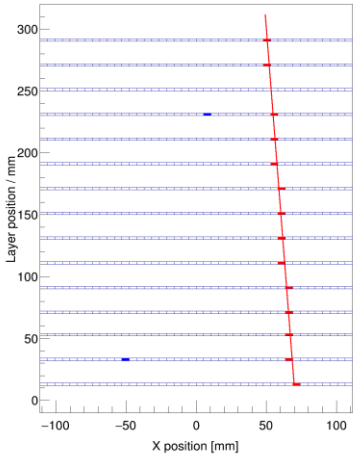
Time resolution of TDC

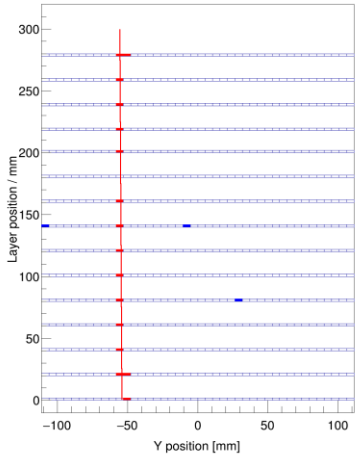
Track finding and fitting

- A preliminary algorithm performed
  - Find and fit the precise cosmic-ray track
  - Distinguish real hit cells and noise cells



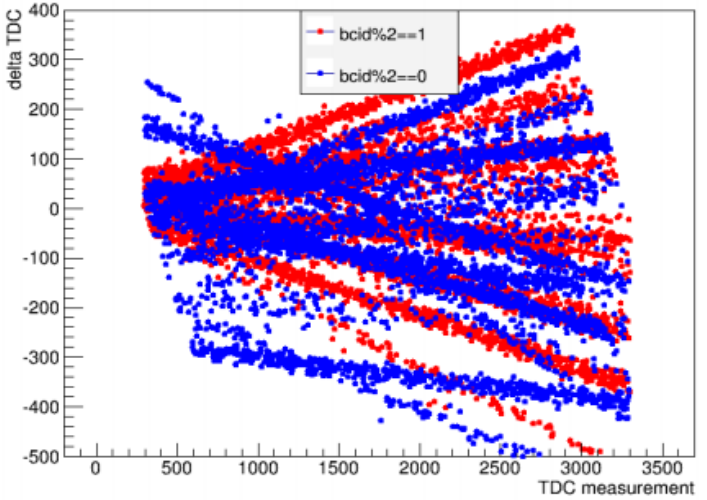
Process	Selection	Efficiency
preSelection	$TotalHitLayer \geqslant 22$	92%
	$TotalHitStrips \leqslant 64$	99.6%
	$ADC \geqslant 5\sigma$	99%
Iteration Fitting	All Hits	
	$Pos - tracking \leqslant (47.5,\ 5,\ 7.5)$	
	Nearest point in one layer	
Track Selection	$\lvert Intercept\rvert \leqslant 114,\ \lvert\varphi\rvert \leqslant 0.7$	98.2%
	$\sigma^2 \leqslant 9.6$	98.3%
	$TotalHitLayer \geqslant 6$	99.8%
Alignment	$Position - trackfittingresidual$	



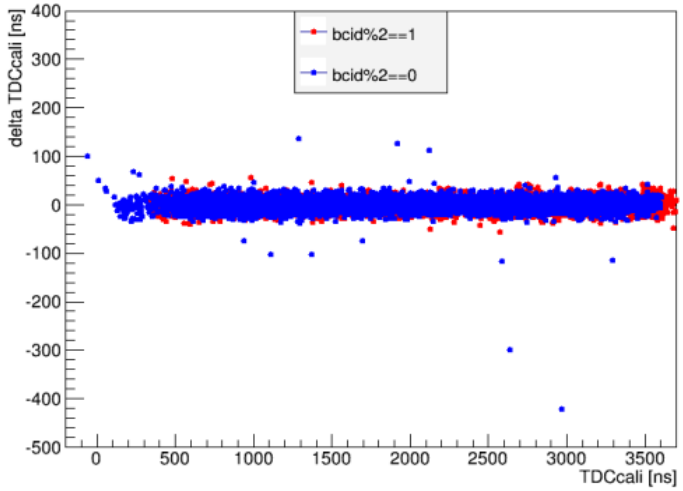


Time Measurement

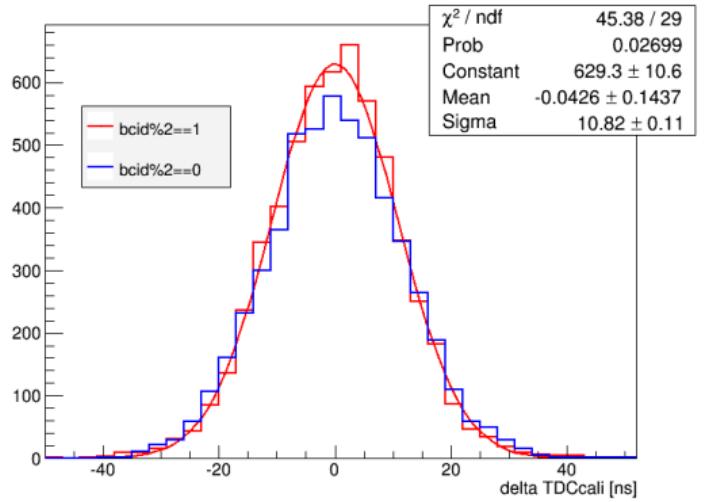
- Here is the time measurement relationship of all chips on the two EBUs
- The time resolution after offset correction is shown
- Both the positive and negative ramp, the time resolutions are about 11 ns after correction



Before offset correction

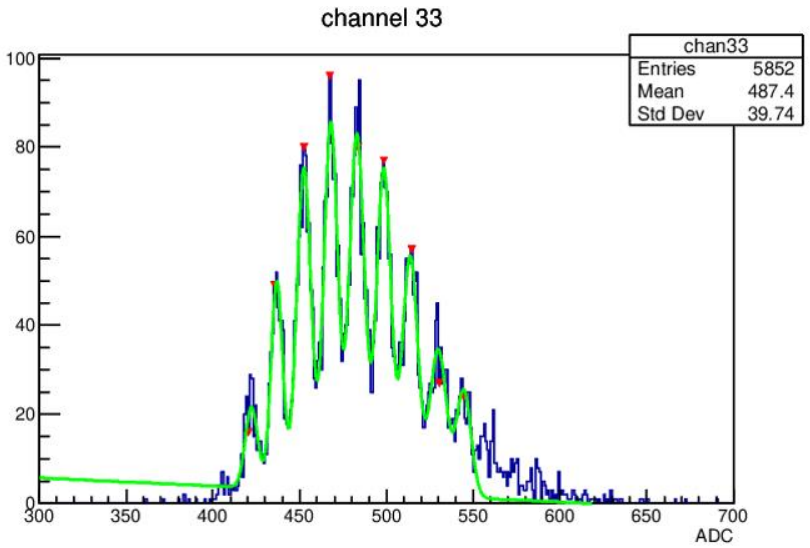


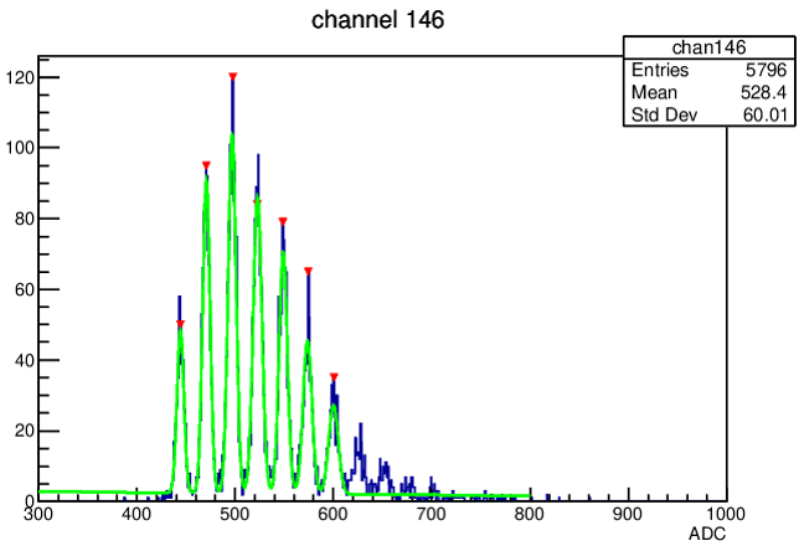
after offset correction



Time resolution

SiPM gain test





Light yield of each channel

- Combined with the SiPM single photon electronic peak obtained from LED test, the light yield of each unit can be obtained
- The light yields using 10um and 15um SiPM readout units are about 10 pe/MIP and 20 pe/MIP, respectively