The Sci-W ECAL technological prototype: construction and tests

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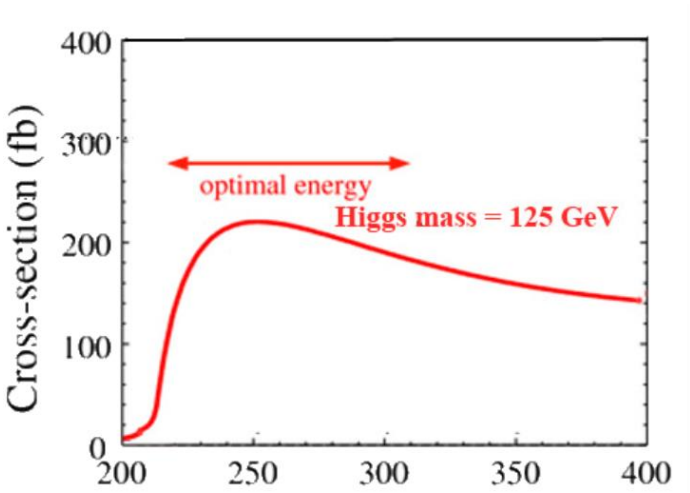
Outline

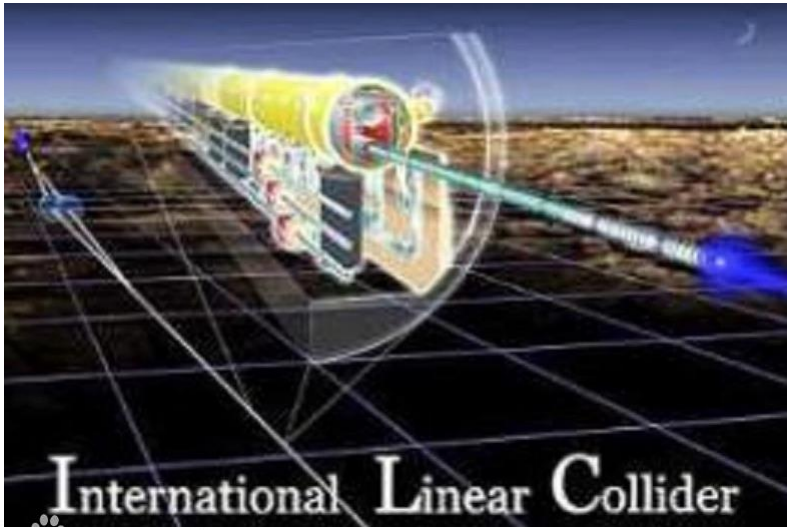
- Motivation
- Sci-W ECAL
  - ECAL Optimization
  - ECAL Development
  - ECAL Performance
- Summary

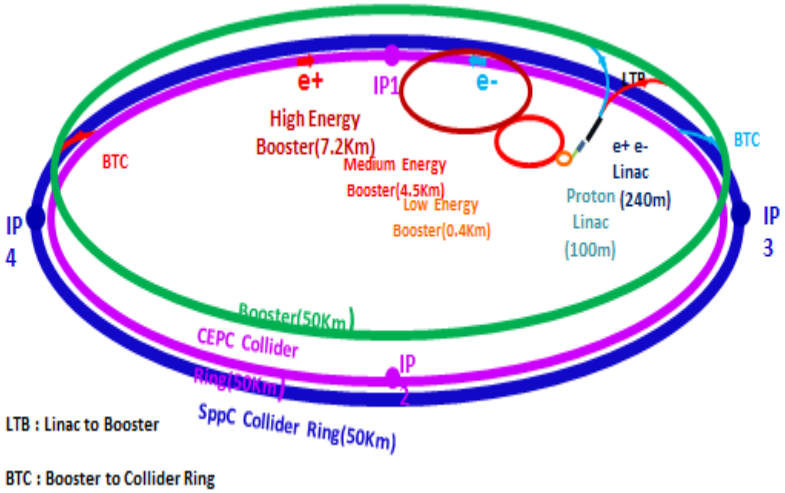
Motivation

Next Generation Collider Experiments have new requirements for the spectrometer, like ILC, CEPC et al.

$e^+e^- \rightarrow ZH$

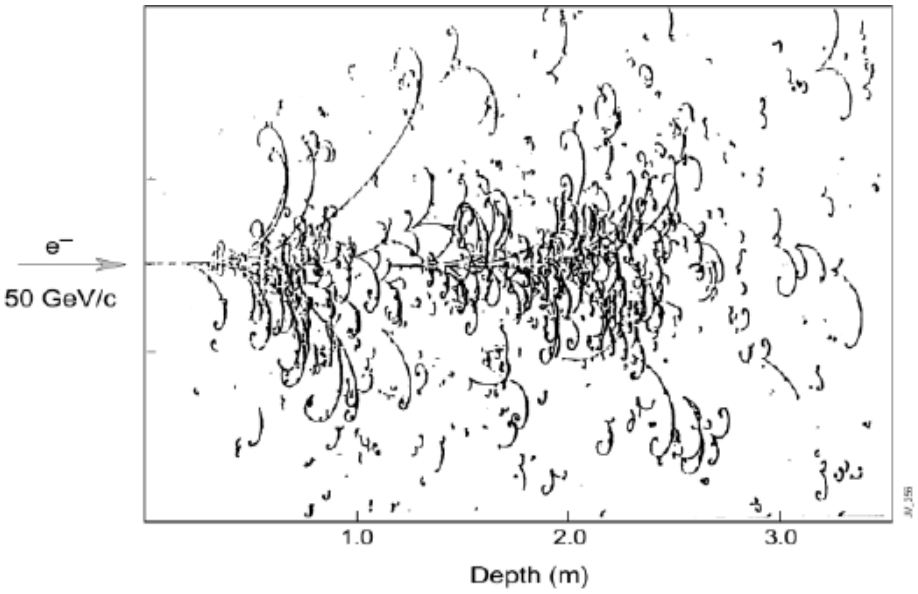






Imaging Calorimeter

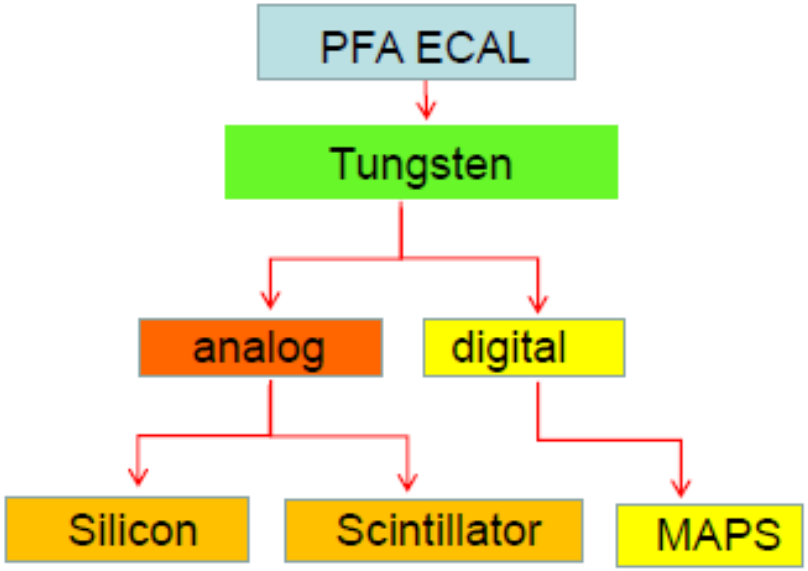
- One option is imaging calorimeter for CEPC
- Challenges
  - High granularity
  - Compact design
  - High power consumption

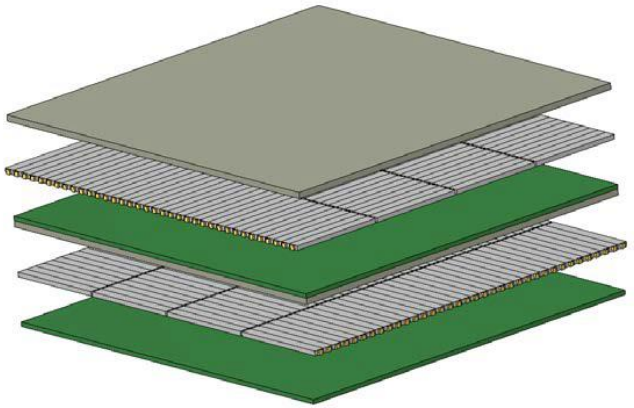


Big European Bubble Chamber filled with Ne:H_2 = 70%:30%, 3T Field, L=3.5 m, X_0≈34 cm, 50 GeV incident electron

Sci-W PFA ECAL of CEPC

- Sampling Calorimeter
  - Sandwich structure
  - Absorber + SD + Electronics
- Absorber
  - Tungsten
- Sensitive Detector
  - Plastic Scintillator + SiPM
- Electronics
  - SPIROC2E ASIC Chip





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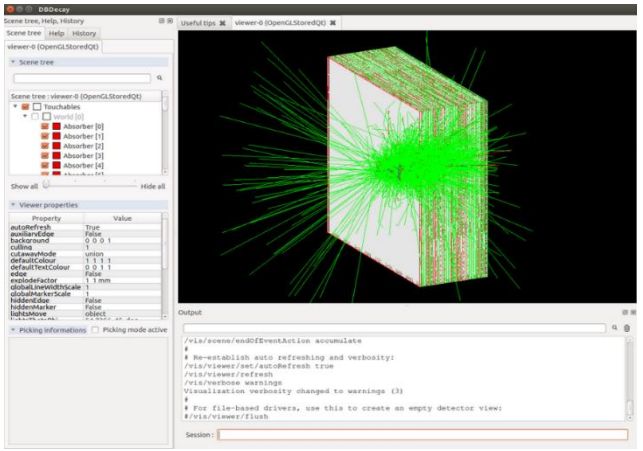
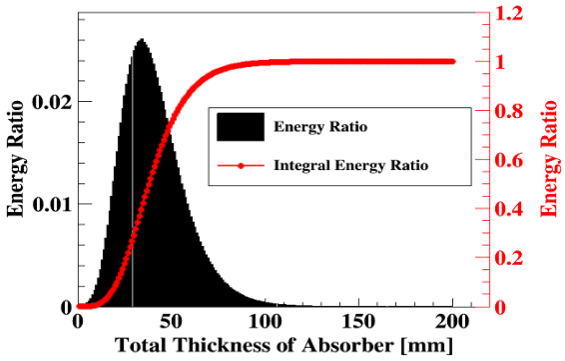
ECAL Optimization

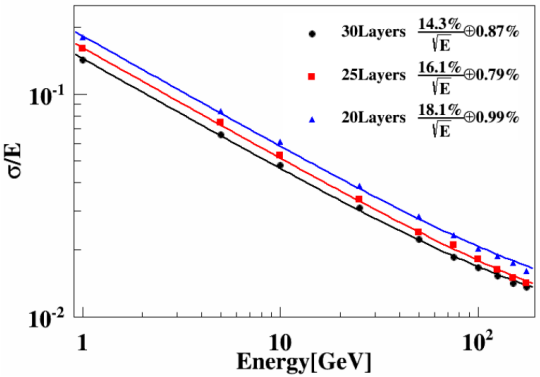
- Total thickness: 24 X_0
- Sampling number: 30 layers
- Granularity: <10mm*10mm



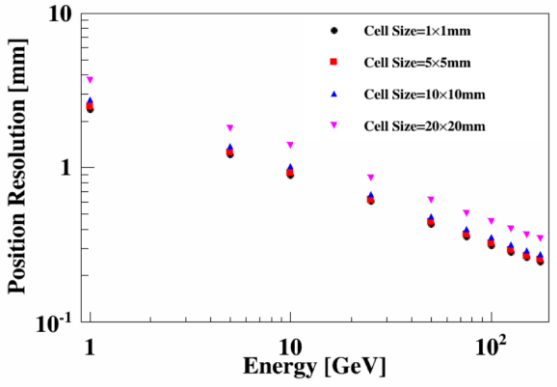
Total radiation length



Sampling number



Cell size



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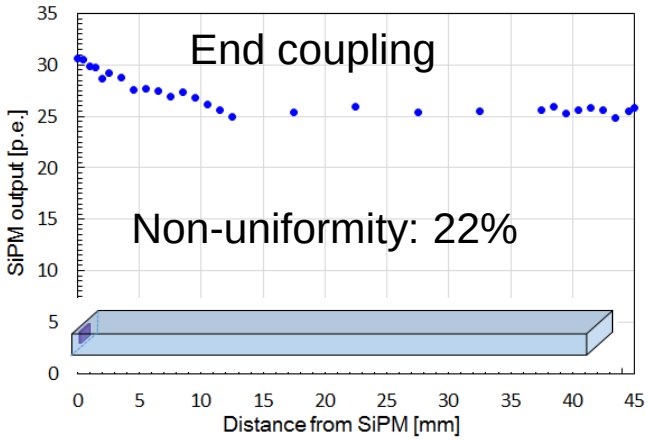
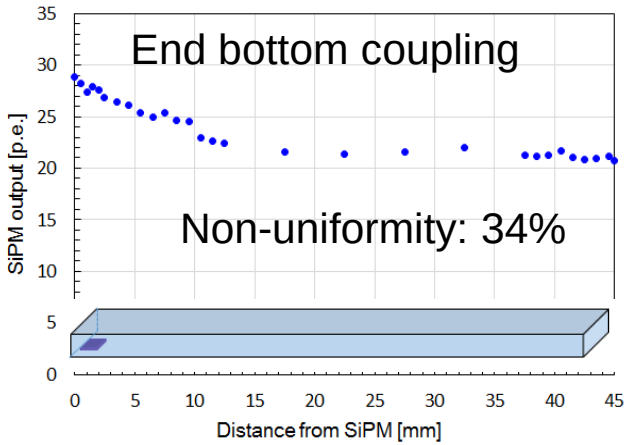
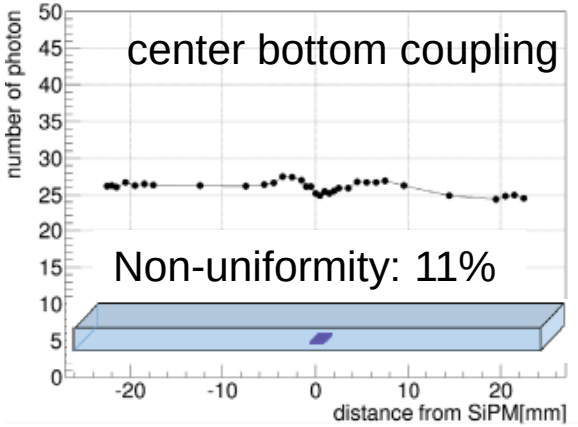
Scintillator



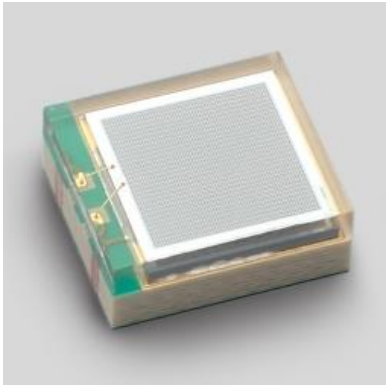


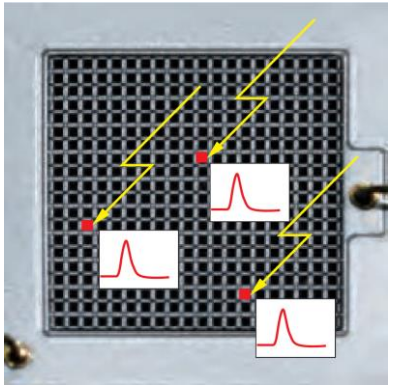


- Three classes coupling mode i.e. side-end, bottom-end and bottom-center
- Light outputs along the length of the scintillator strip is non-uniformity, degrades the energy resolution
- Bottom-center coupling have the minimum non-uniformity
  - Avoiding the dead area between scintillators
  - Simplifying scintillators assembling process
  - Enabling to extend the SiPM area with more pixels

SiPM

LED test system was built to test the SiPM





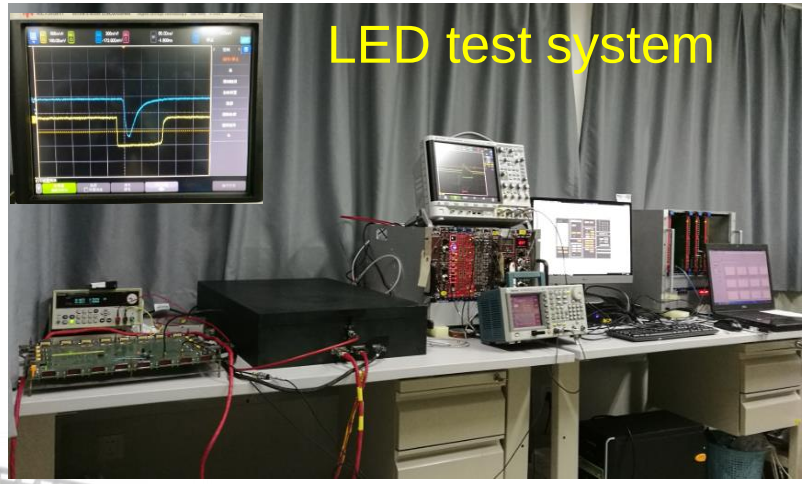
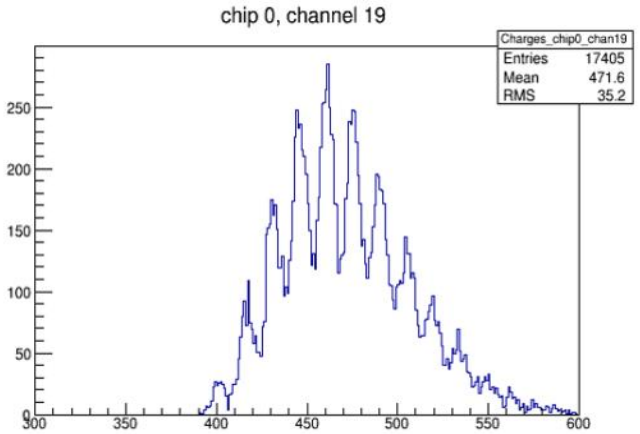
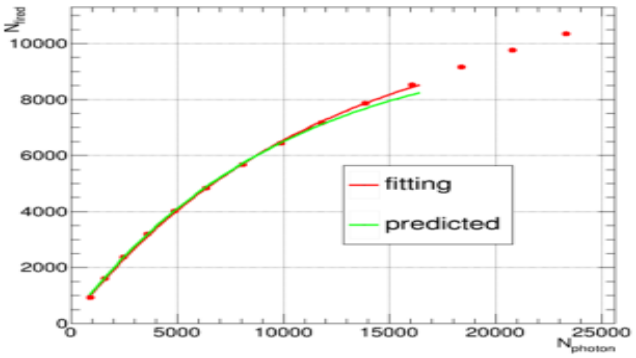


Photo-electric spectrum

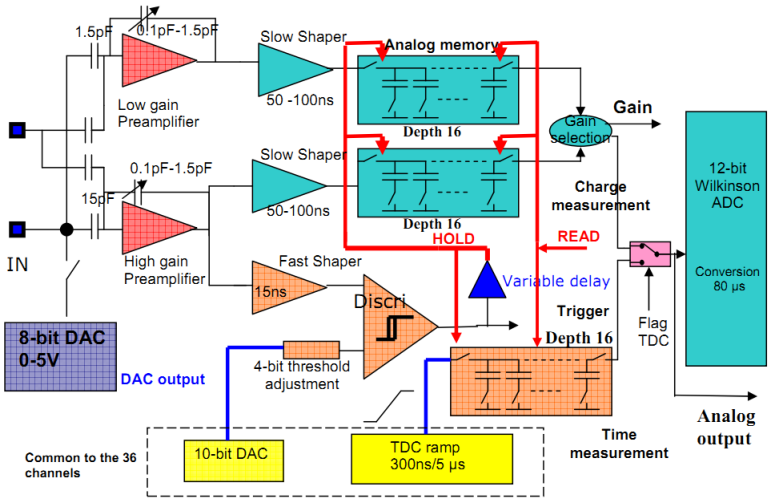


SiPM linearity



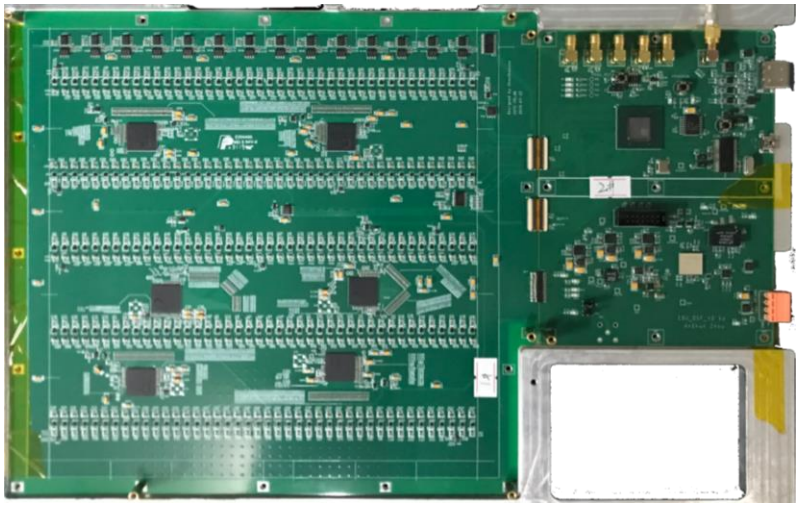
Readout Electronics

- **SPIROC2e** chip has 36 channels
- Switched capacitor array store charge
- 12 bits ADC conversion
- Variable Gain due to:
  - adjustable C_f of pre-amplifier
  - Shaping time and delay



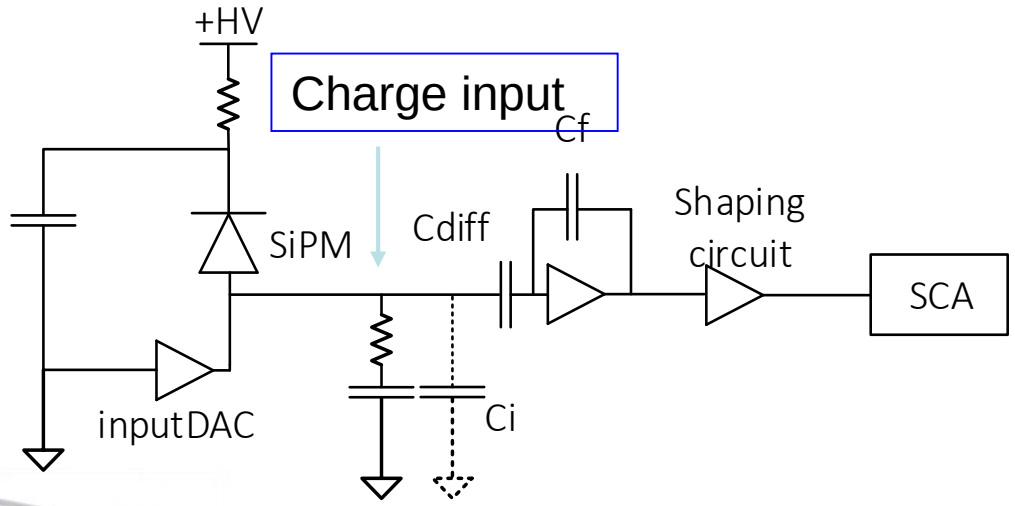
- Three additional functions were designed in the ECAL EBUs
  - DAC calibration
  - LED calibration
  - Temperature monitor and compensation

EBU DIF

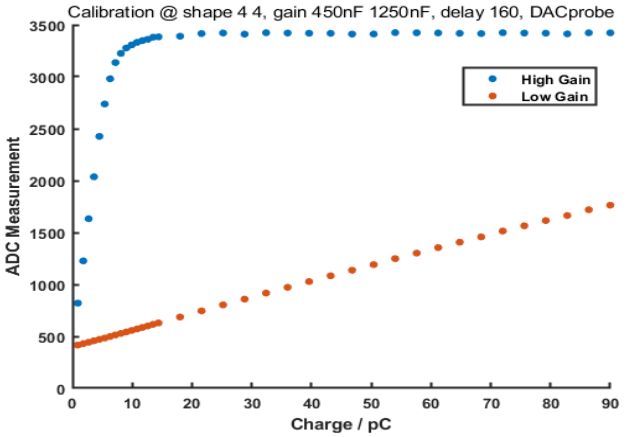


Electronics I

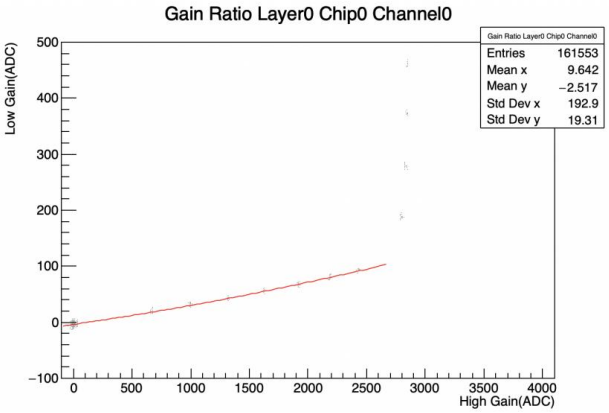
- DAC calibration
  - to calibrate the linearity of readout channels, both the high gain and low gain channels
  - Also could be used to calibrate the ratio of low gain and high gain channels



Linearity of readout channels

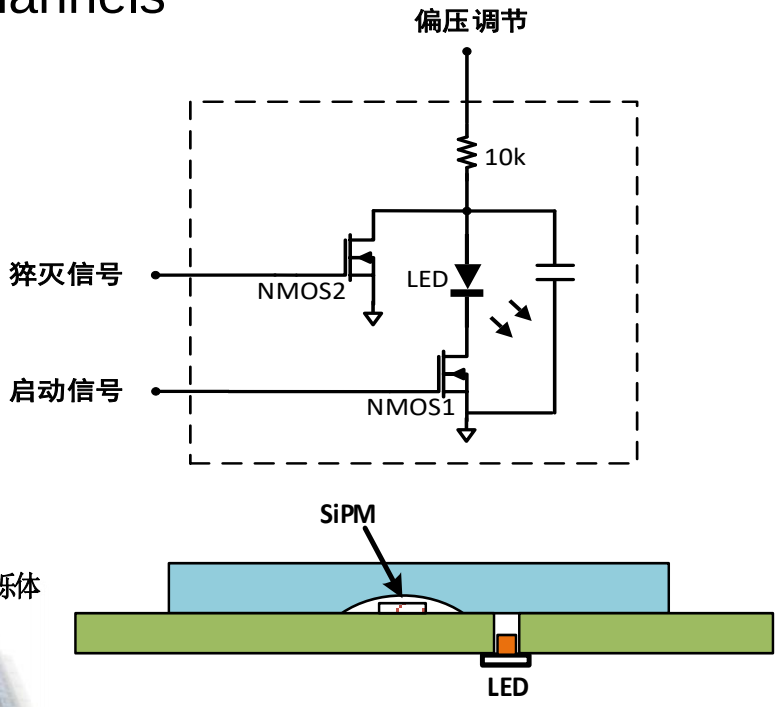


Low gain high gain ratio

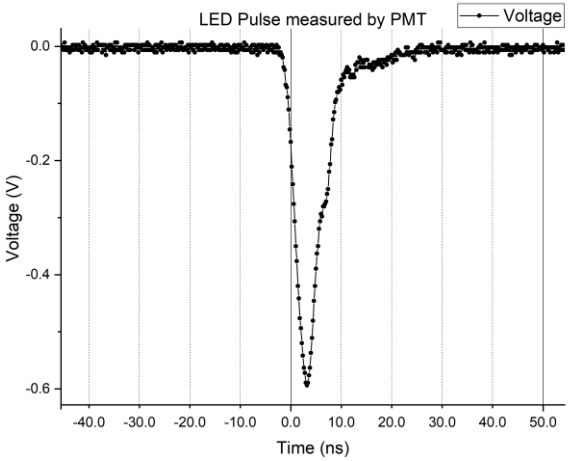


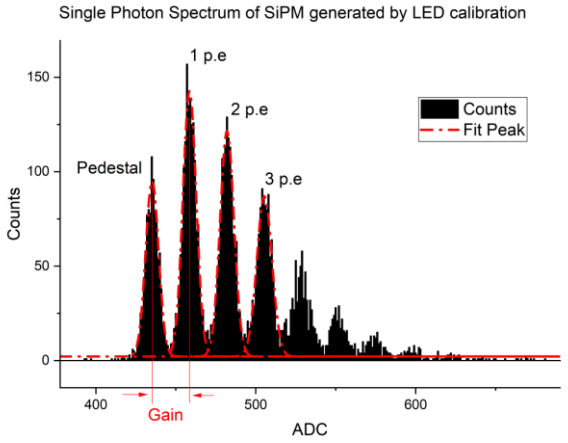
Electronics II

- LED calibration
  - The LED was put near the SiPM
  - A circuit was designed to drive LED to calibrate SiPM, like the photo-electron peaks, the ratio of low gain and high channels



LED light spectrum

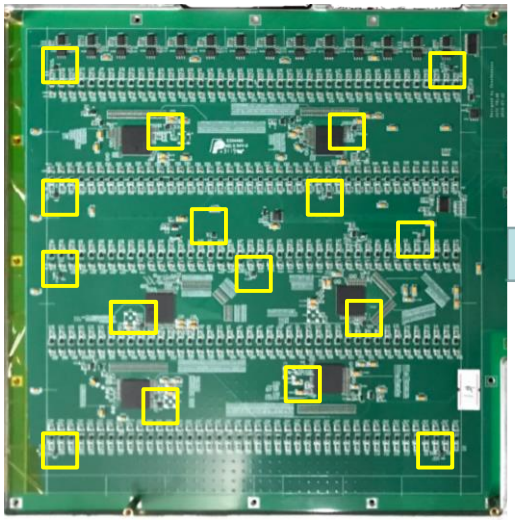




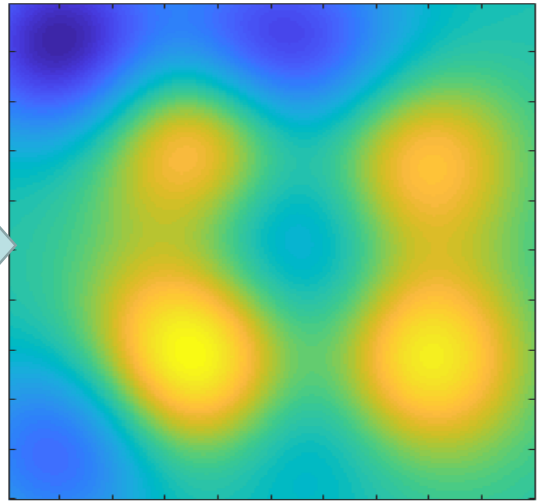
SiPM photon electron peak

Electronics III

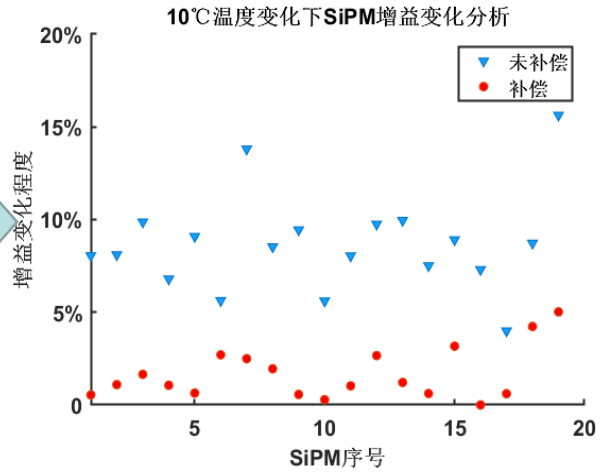
- Temperature monitor
  - Each EBU has 16 sensors to monitor the temperature
  - reconstruct the temperature field using these data
  - and to adjust the gain of SiPMs on the board (operation voltage)



Temperature sensors



Temperature field



Gain stability after compensation

Single Layer assembly

Cutting

Grooving

Polishing

Annealing

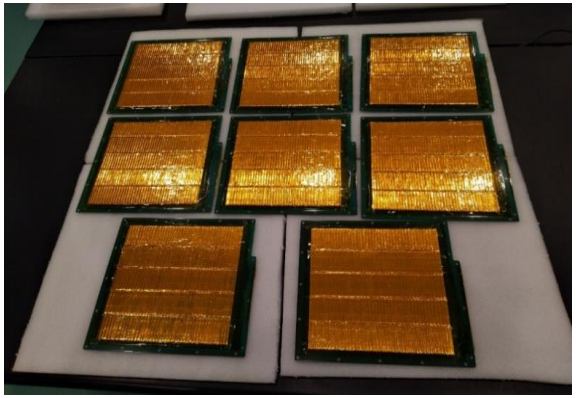
Cleaning

Packing

Visual inspection

cleaning

assembling

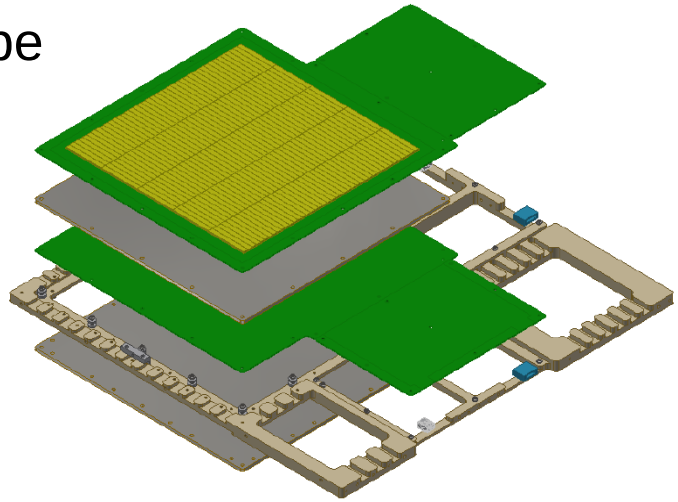


EBU

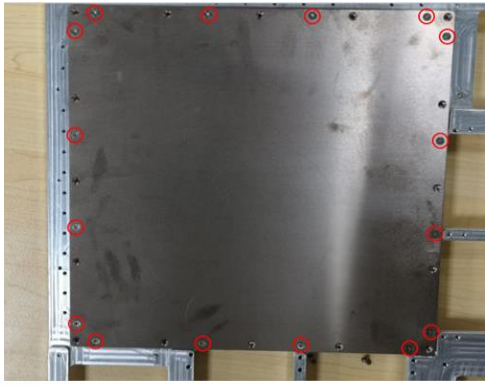
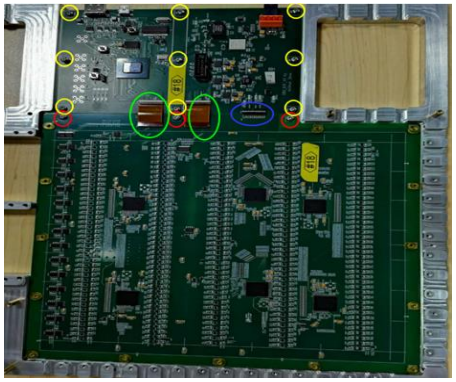
The single layer prototype was assembled in Shanghai Institute of Ceramic (SIC)

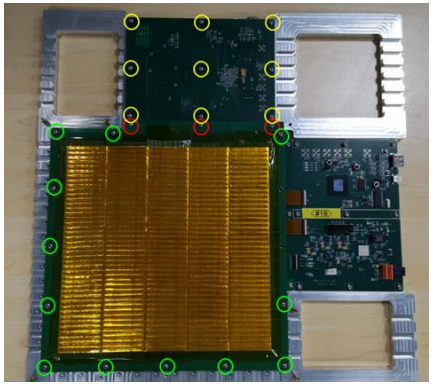
super-layer assembly

- There are 16 super-layers in ECAL prototype
- Each super-layer has 2 Ecal Board Units (EBU) and 2 Data InterFace boards (DIF)
- Also has 2 W-Cu alloy plates, W:Cu 85%:15%, thickness is 3.2 mm ~ 0.73 X_0
- The aluminum frame is used to support the super-layer

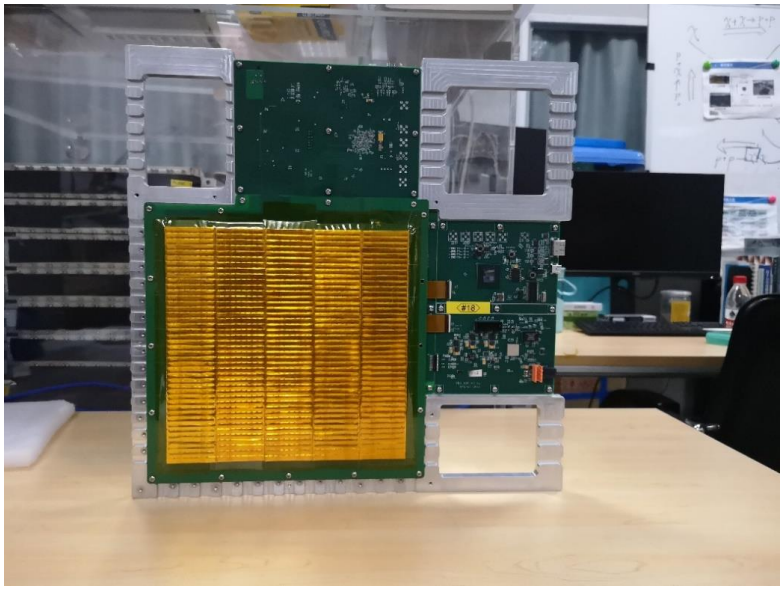


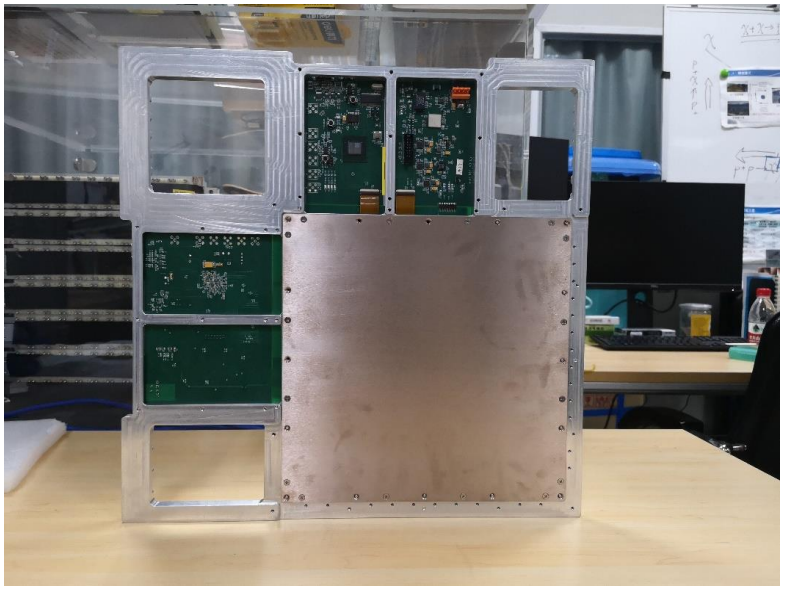
The structure of super-layer

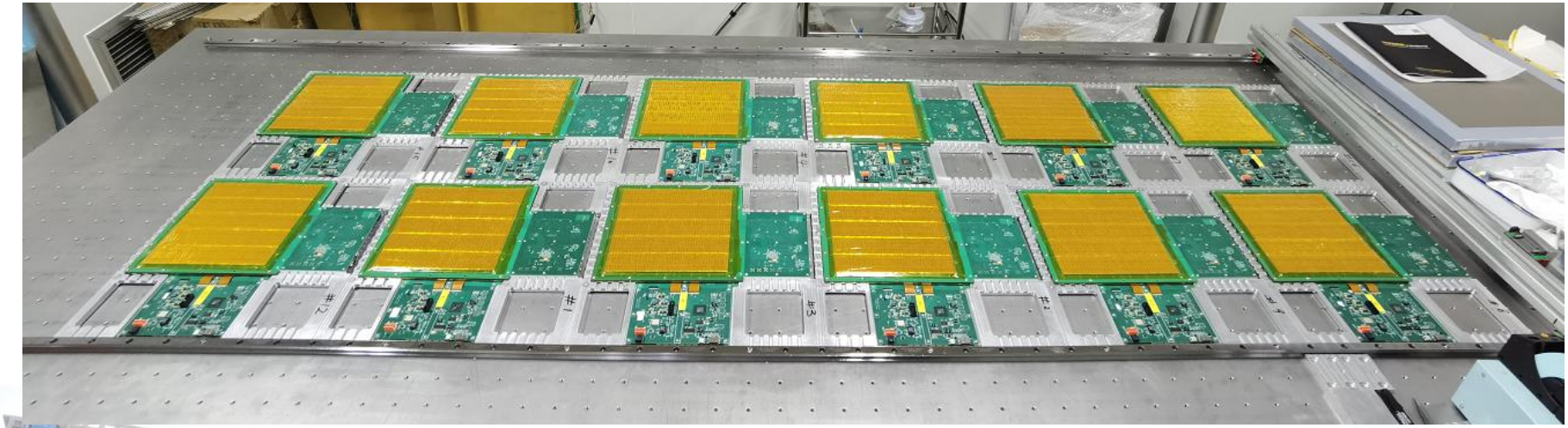





Super-layer assembly

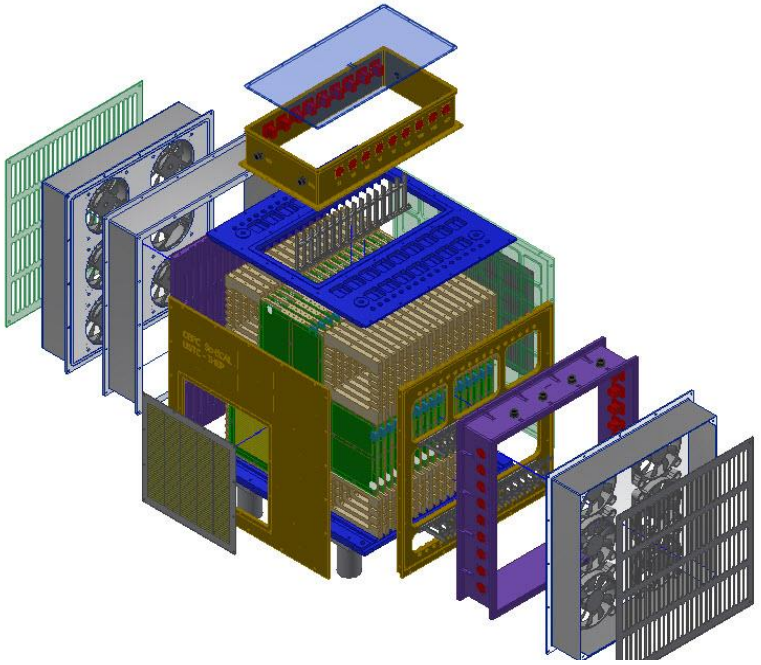


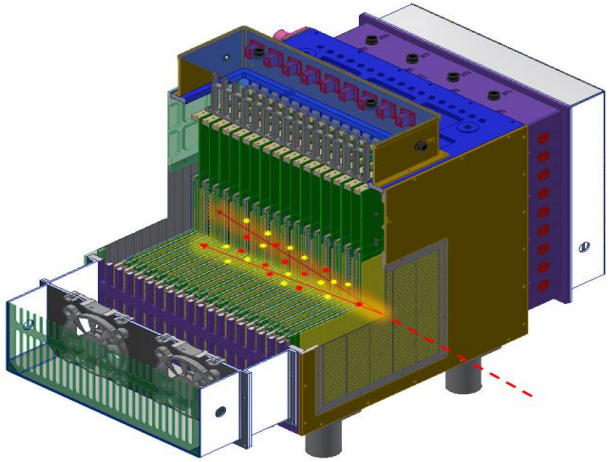




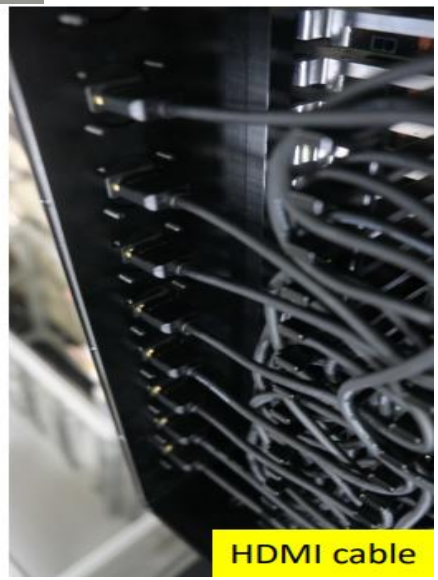
Calorimeter assembly

- The calorimeter prototype has 16 super-layers
- The total radiation length is about 23.4 X_0
- The adjacent layers are arranged in orthogonal order to ensure the 5 mm granularity
- The gap between two super-layers is smaller than 1 mm
- There are 12 fans on two sides to dissipate heat





Calorimeter assembly



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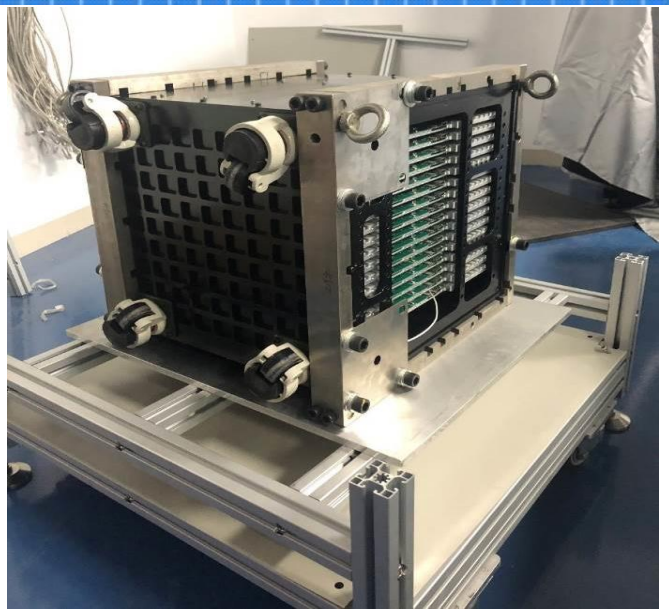
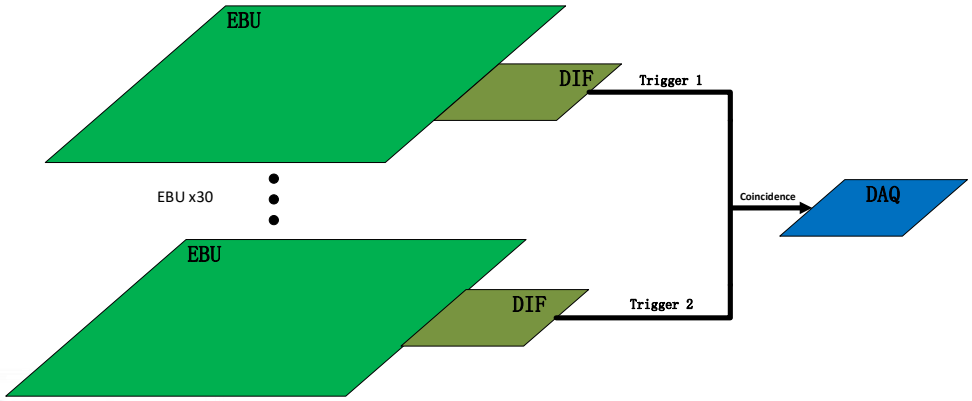
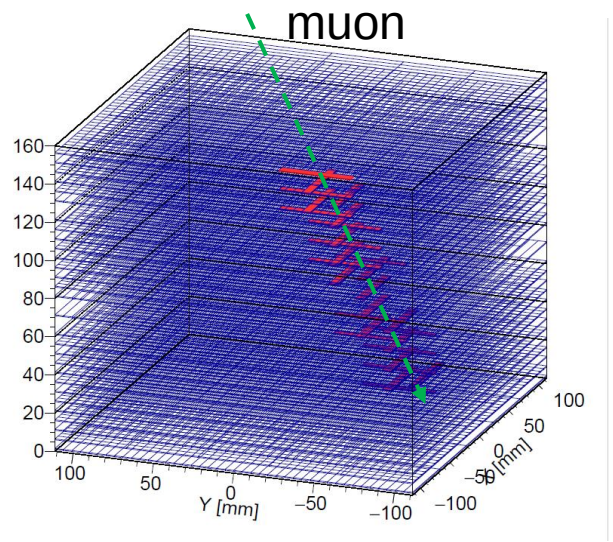
Cosmic Ray test

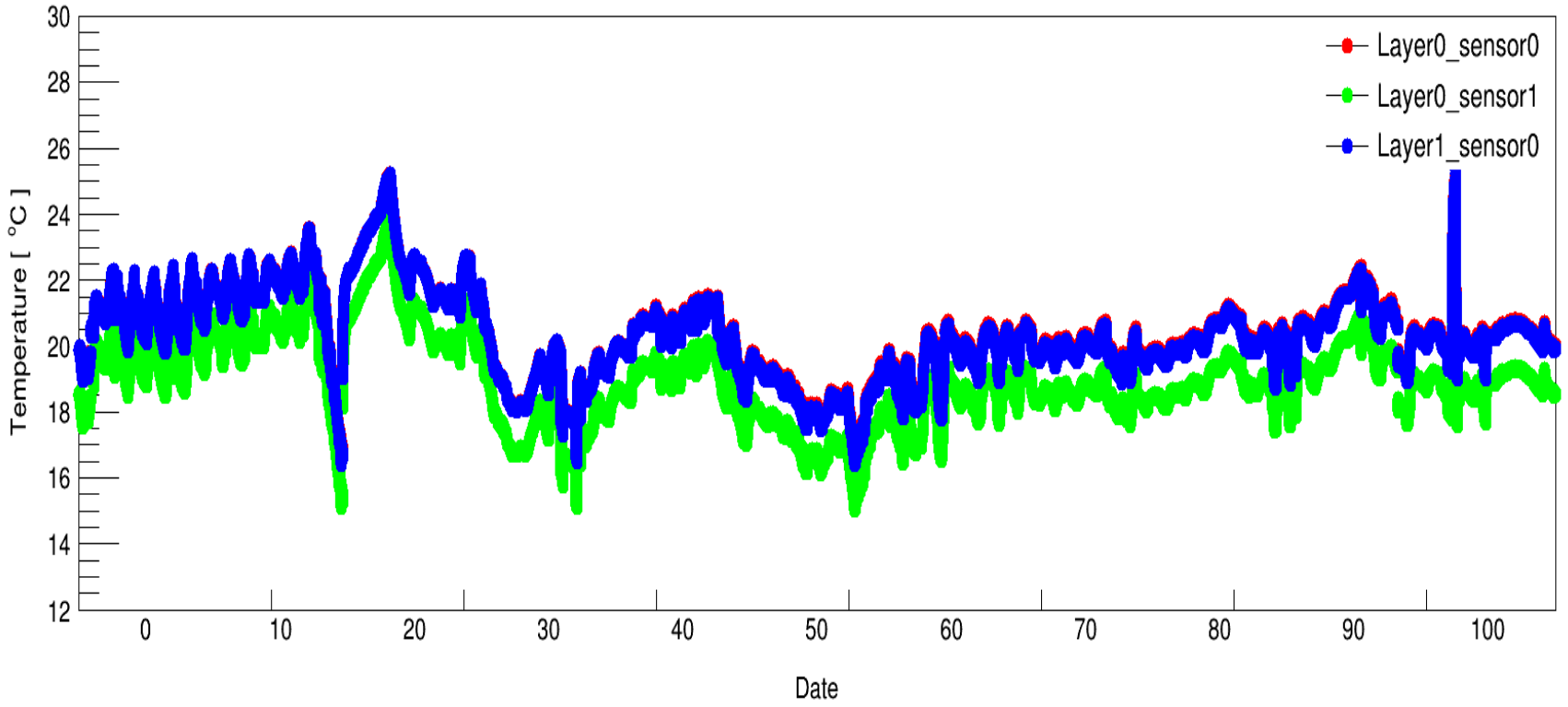
- Long term cosmic ray test: 90 DAYs
  - ScECAL has been rotated by 90 degree
  - Coincidence trigger of Layer1 & Layer29
  - Event rate : ~ 16 per minute
  - ~1.5 million cosmic ray events collected
- Purpose
  - Function verification (stability, temperature correction, etc)
  - EBU efficiency and Position resolution
  - Cell-to-cell MIP calibration







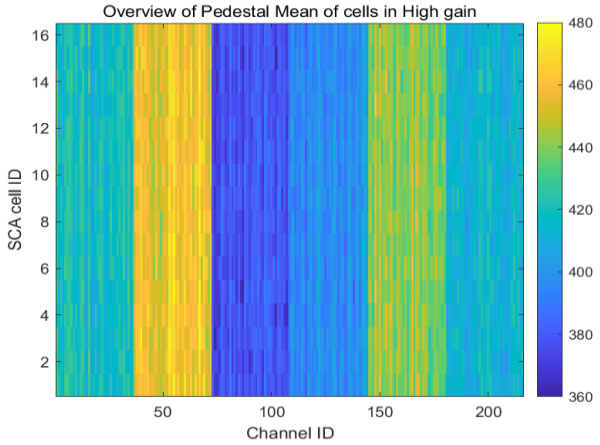
Temperature



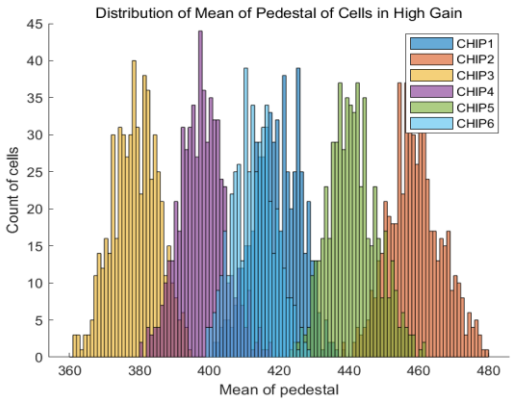
- The temperature is between 14 and 20 degrees, with an average of 20 degrees
- At first the test room with relatively good temperature control conditions
- Most of the time, the temperature control condition of the room is not good

pedestal

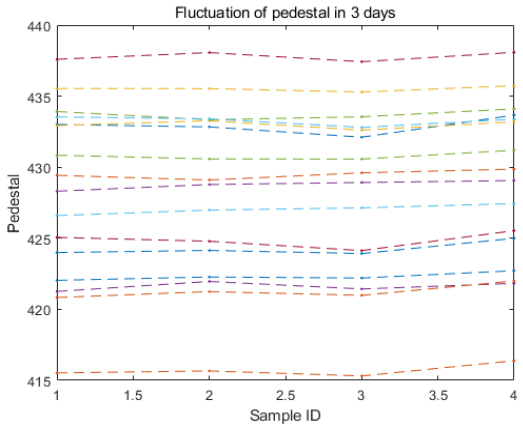
- The noise of each cell in each channel tested by random trigger from DIF boards
  - The pedestal position of different chips is a little different
  - The pedestal position of the same chip is more uniform
  - The pedestal position is very stable with the change of time



Pedestal position of each cell in each channel



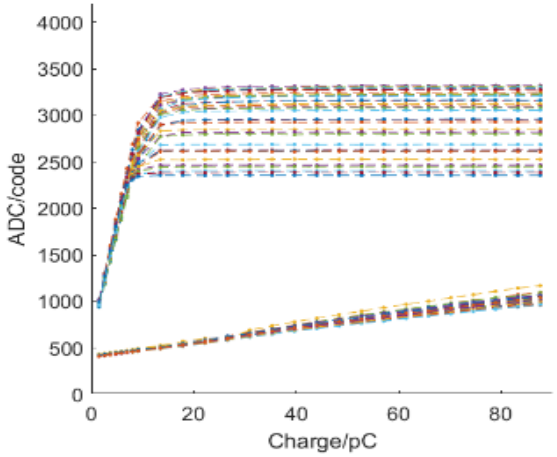
Pedestal position distribution of each channel



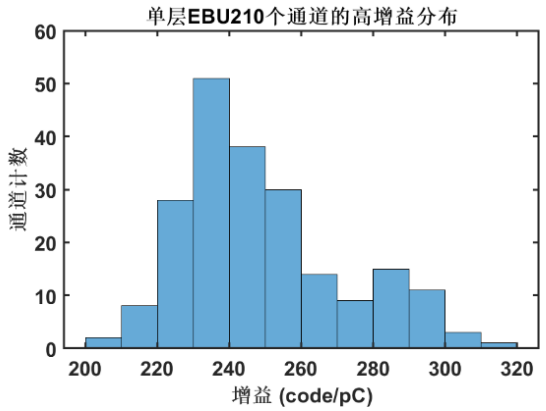
Pedestal position stability

DAC calibration

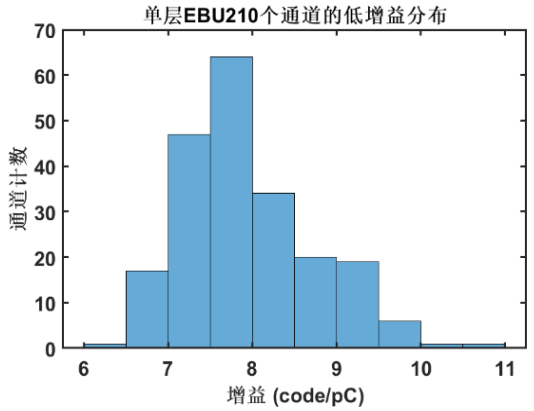
- The readout linearity
  - The high and low gain channel could achieve the upper limit of 10 pC and 100 pC respectively
  - The gain coefficients of high and low gain are about 240 and 8 code/pC respectively, and the ratio of high and low gain is about 30.



Linearity of the high/low gain channel



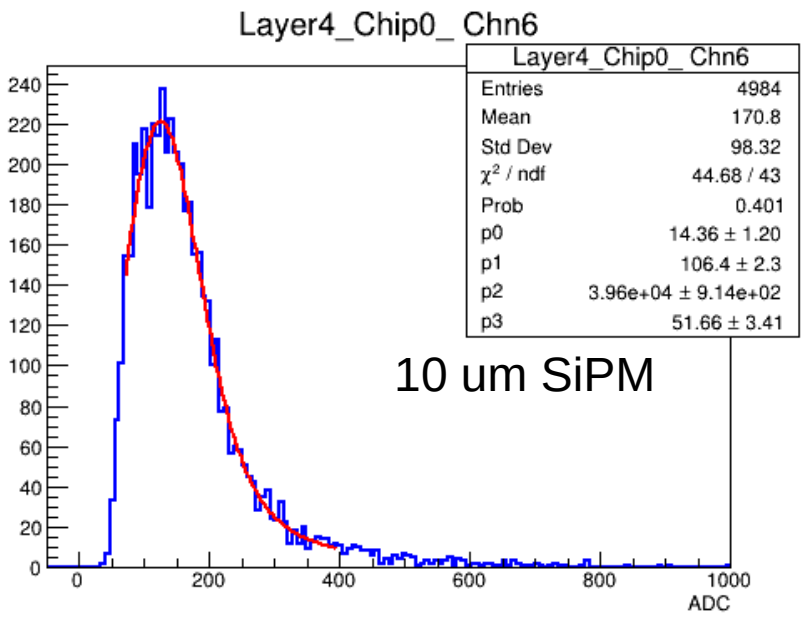
The high gain channel factor

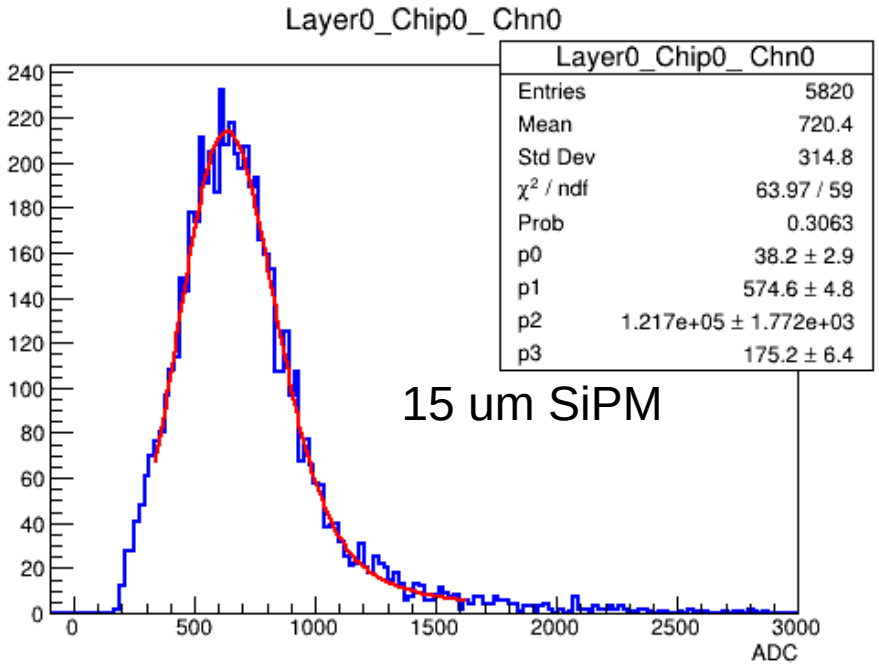


The low gain channel factor

MIPs Spectrum I

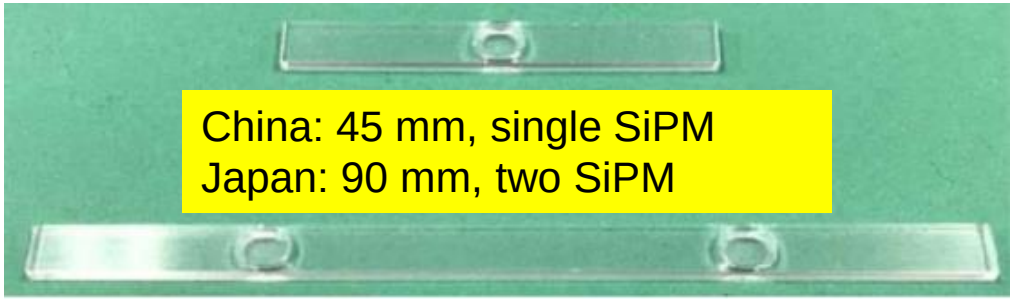
- MIPs spectra measured by 10um and 15um SiPM can be seen clearly
  - The amplitude of 10 um is about 100 ADC counts, and 600 ADC counts for 15 um SiPM (After subtracting the pedestal)

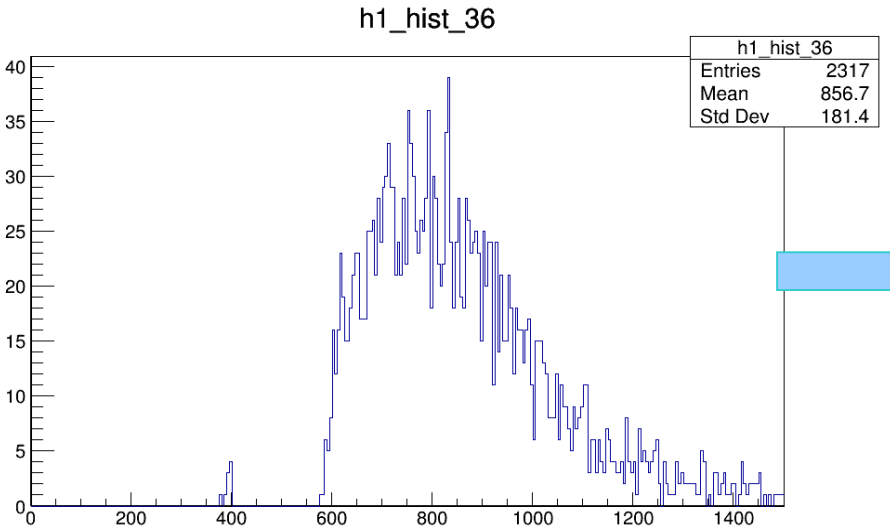




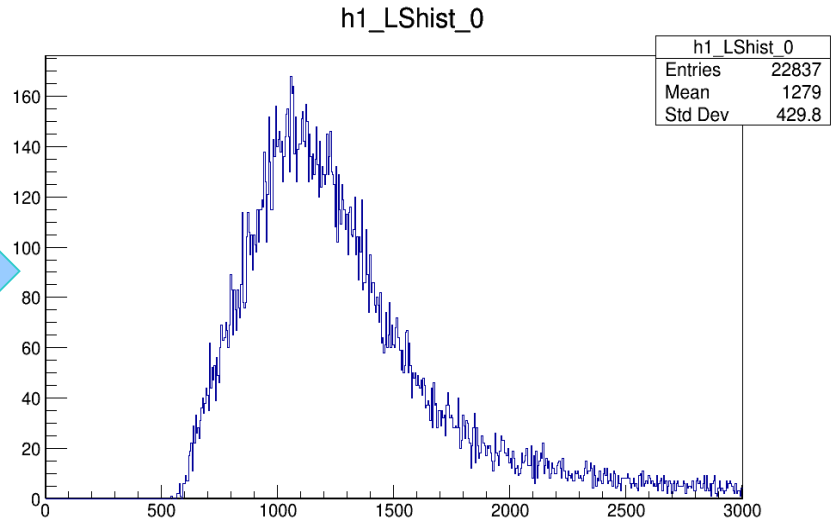
MIPs Spectrum II

- The calorimeter prototype has two layers designed by our Japanese colleagues
  - a long strip (90 mm) coupled with 2 SiPMs, both are 15 um





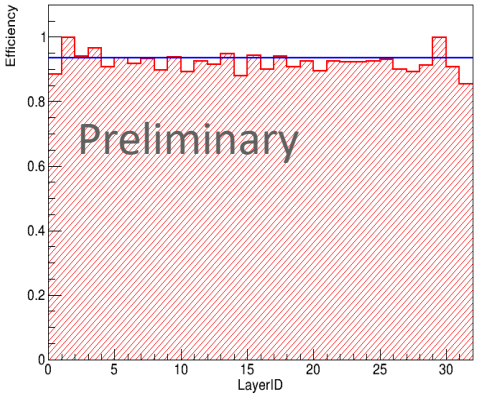
One SiPM amplitude

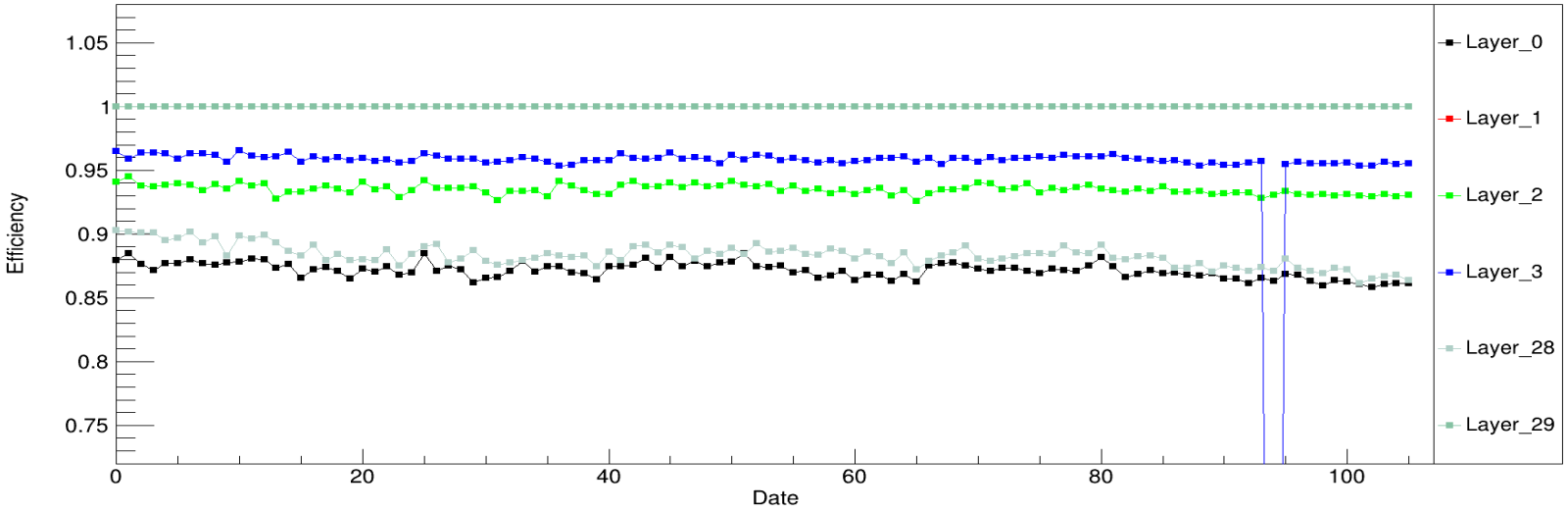


Sum of two SiPM amplitude

Detection efficiency

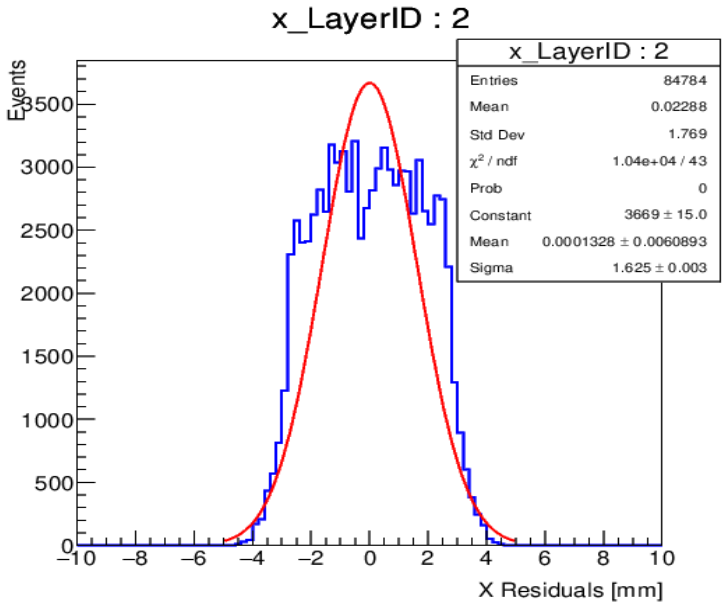
- Efficiency achieve about 90% for all layers
  - Layer 1 & 29 are trigger layers
  - Sensitive area is about 93.5%
  - Affected by the MIP threshold
  - Stable continuous for long period operation

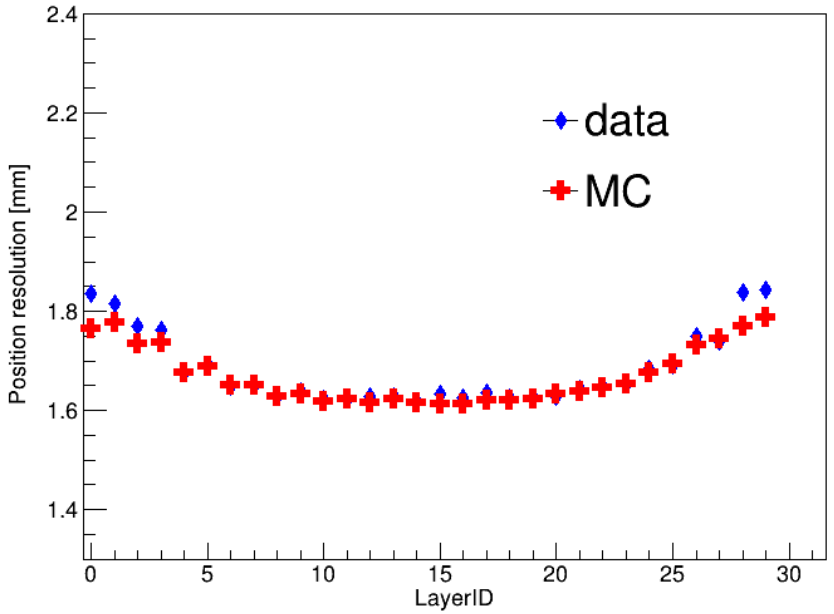




Position resolution

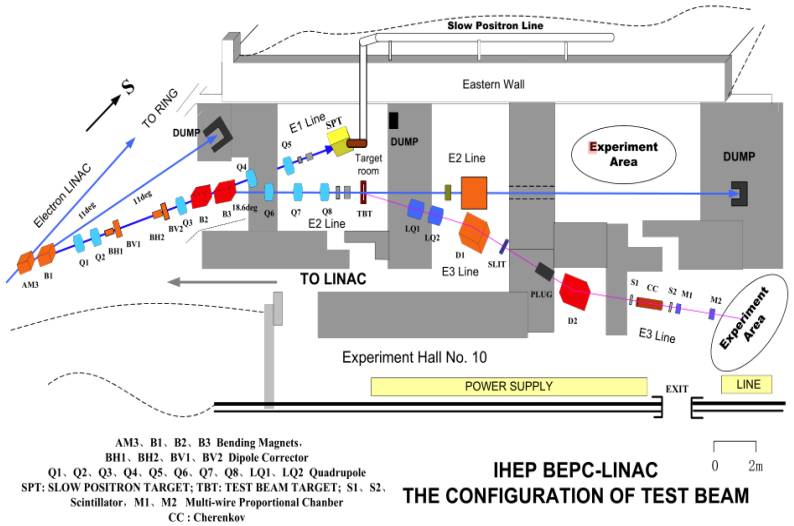
- Position resolution better than 2 mm
  - Strongly affected by large angle scattering
  - The RMS of residual distribution is referred as the position resolution
  - The settings of simulation should fine tuning

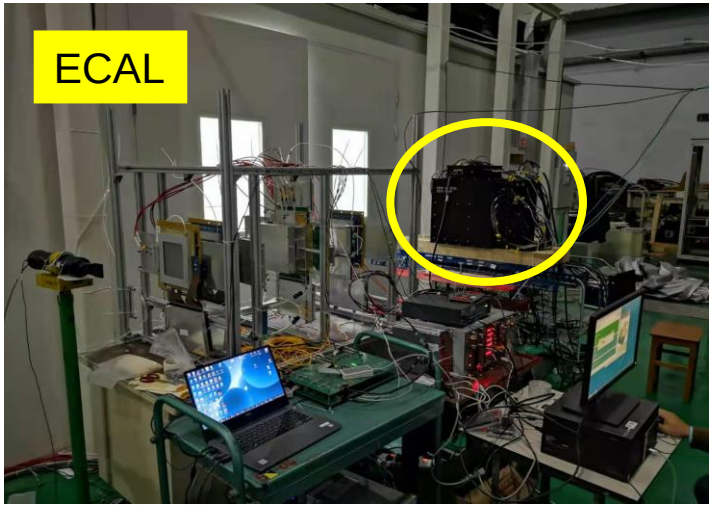


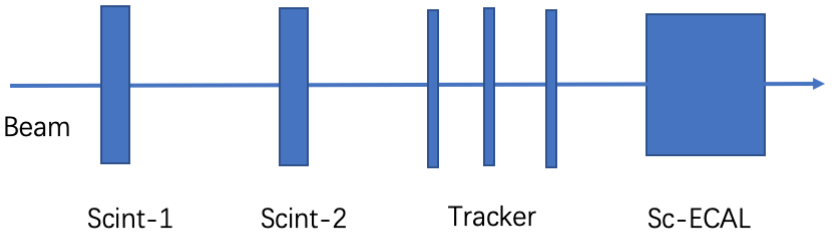


Beam Test in IHEP

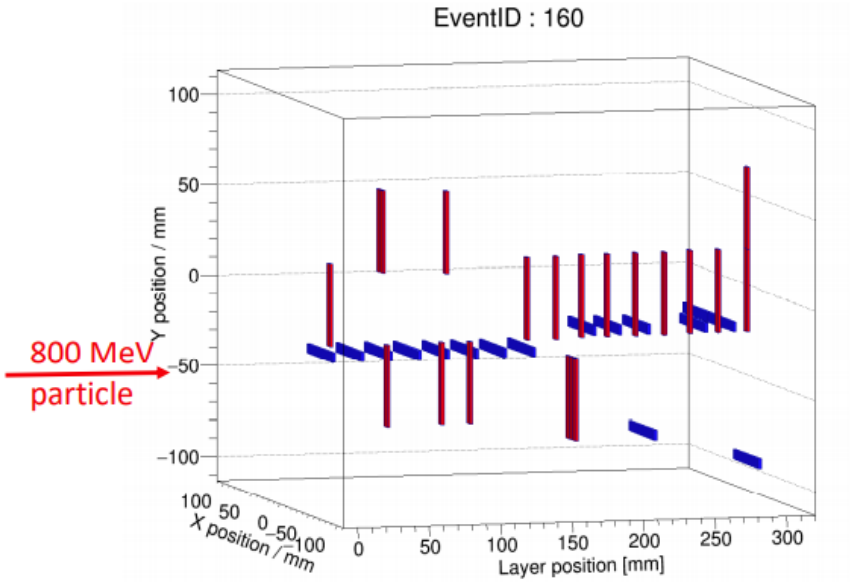
- E3 beam line
- 2.5 GeV e- interacted with Be target
- Three momentums were selected in the beam
  - 500 MeV/c, 800 MeV/c, 1000MeV/c

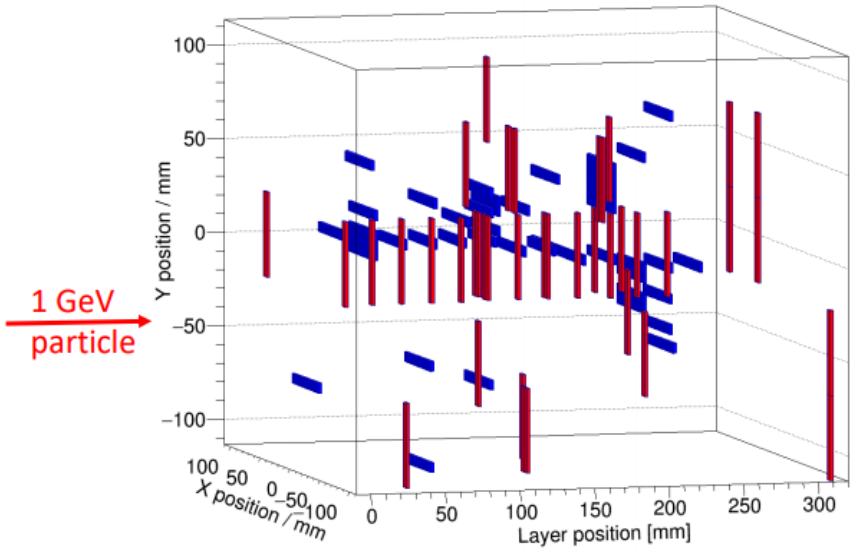


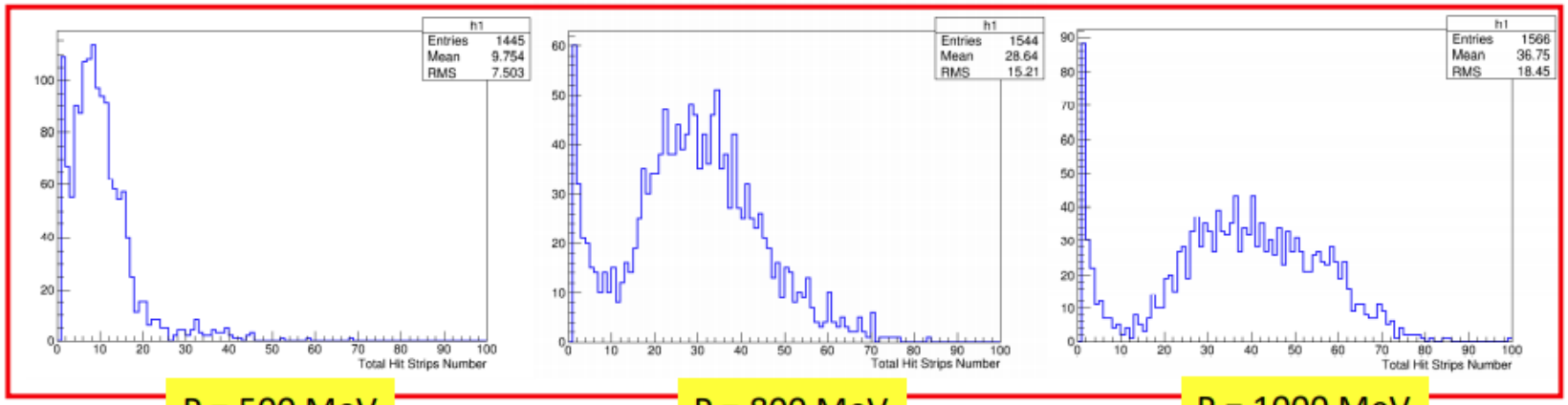




Beam Test in IHEP







P = 500 MeV | P = 800 MeV | P = 1000 MeV

Total hits Number in ECAL

Outline

- Motivation
- Sci-W ECAL
  - ECAL Optimization
  - ECAL Development
  - ECAL Performance
- Summary

Summary and outlook

- The imaging calorimeter is one of the options of ECAL of next generation collider experiments
- The prototype based on Sci-W (and SPIROC2E chip) has been developed
  - 32 sampling layers, great than 6000×2 channels
  - The granularity is 5 mm×5 mm
- A simple beam test and long-term cosmic ray test have been carried out
  - The results show that the performance of the prototype is good
  - the design functions can be realized
    - The noise, MIPs amplitude, temperature…
- Next step, we hope to carry out the beam test in near future
  - Desy, CERN, IHEP

Summary and outlook

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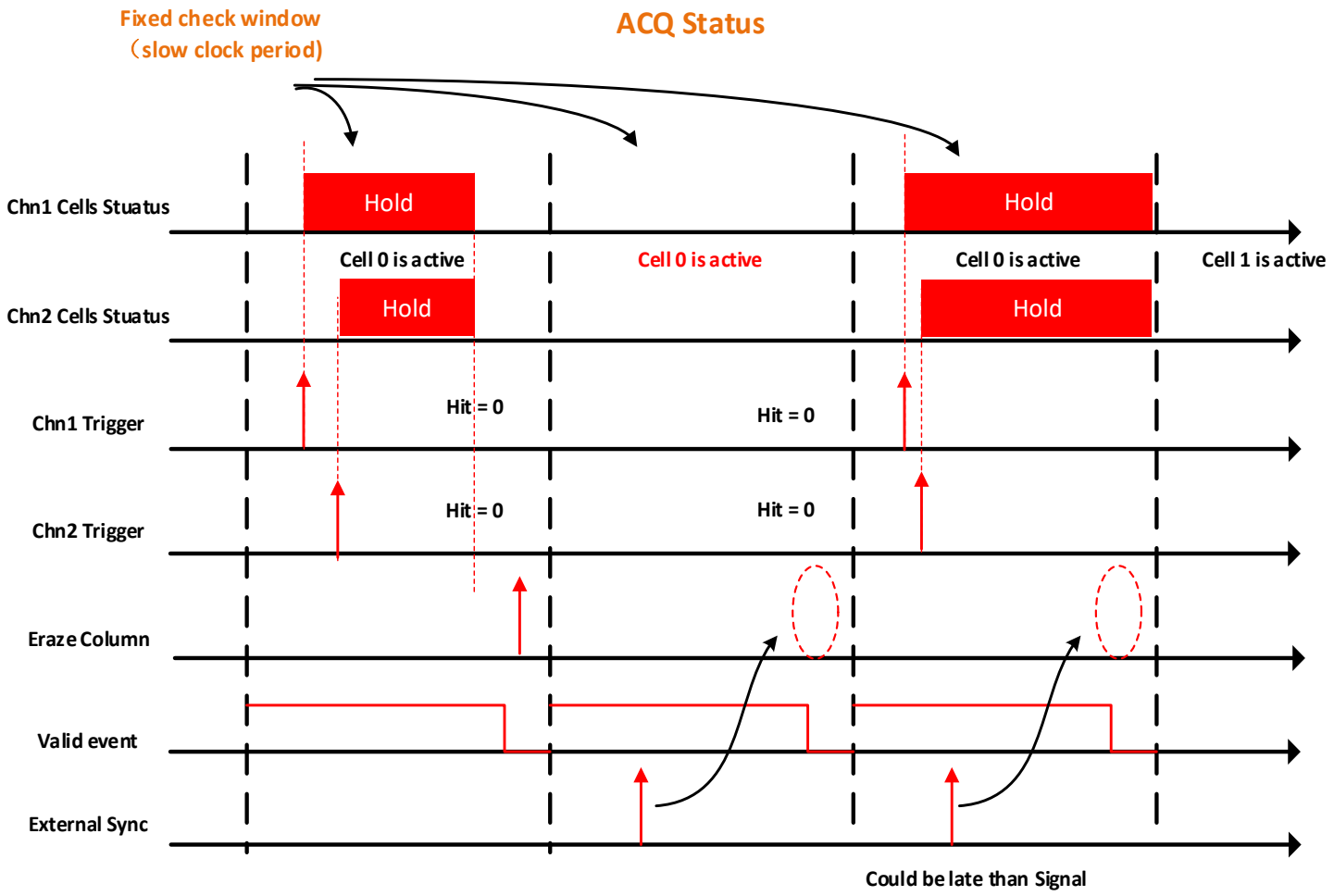
THANKS

backup

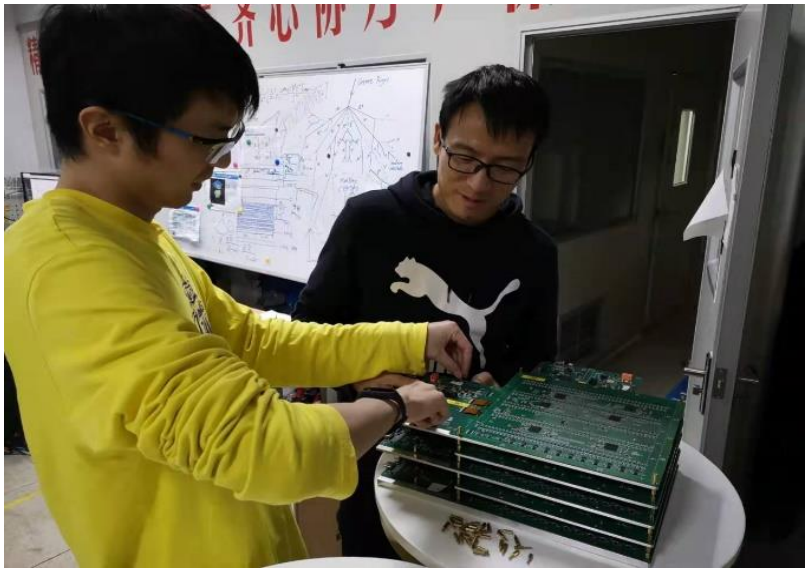
ECAL trigger



Validation Mode

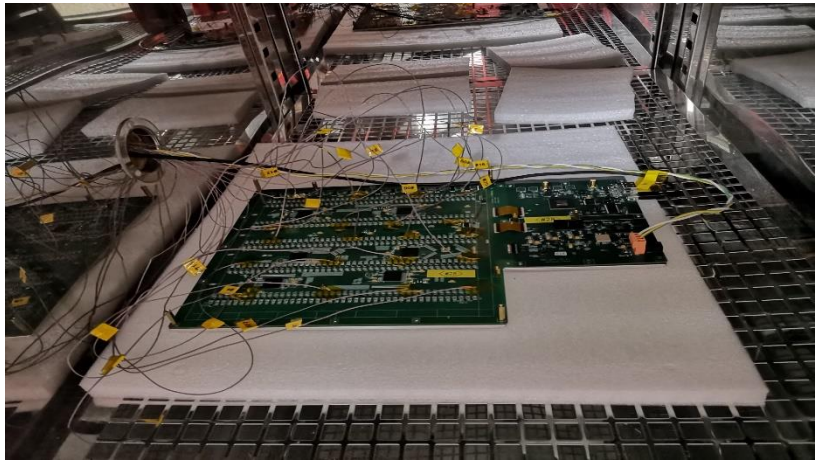
EBU Test

- Aging Test
  - 50+/-2 degree
  - 48 hours



Temperature correction

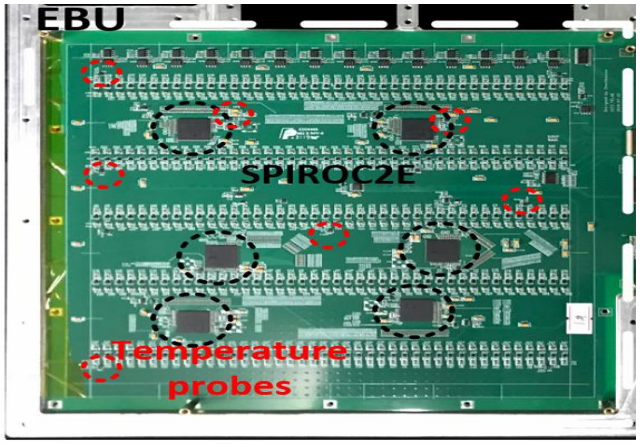
- In order to check this interpolation method, 20 thermocouples are pasted on the EBU to monitor the temperature change on the EBU in different position.
- Put the EBU into a high and low temperature box, and change the temperature from 20 - 45 degree.
- Both the temperature sensors of EBU and the pasted thermocouples could measure the temperature in real time



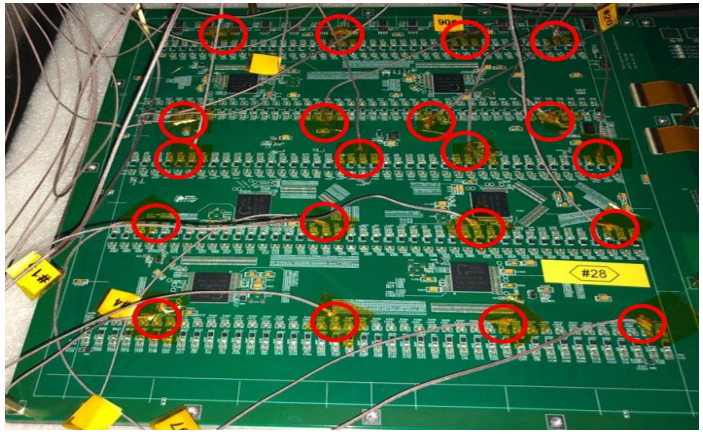
EBU in the high-low temperature box

Temperature correction

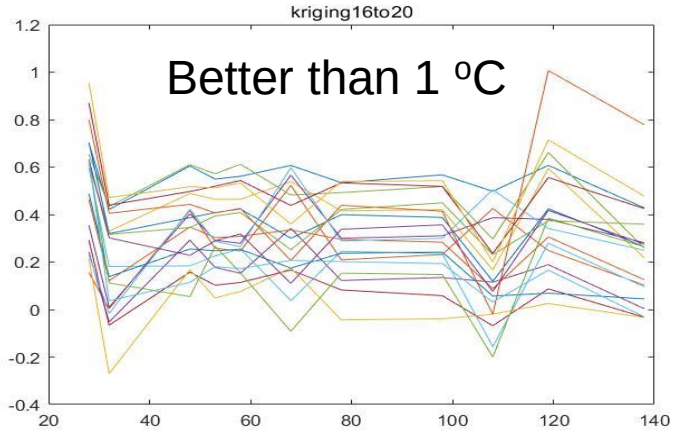
Position of temperature sensor of EBU



Position of the pasted thermocouples



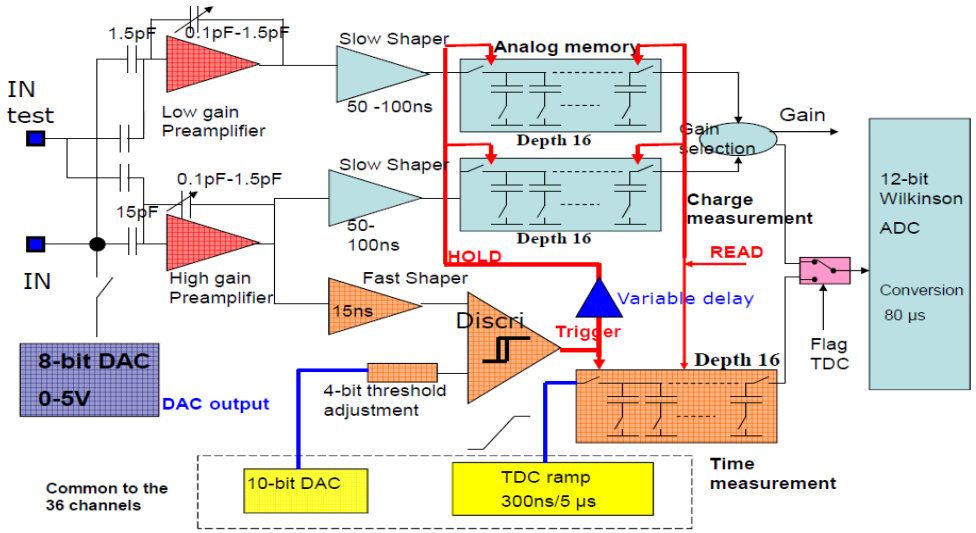
- According to the temperature measured by the sensors on the EBU, the temperature of the thermocouple position is calculated by interpolation method using the values of these sensors and compared with it measured by thermocouple itself.

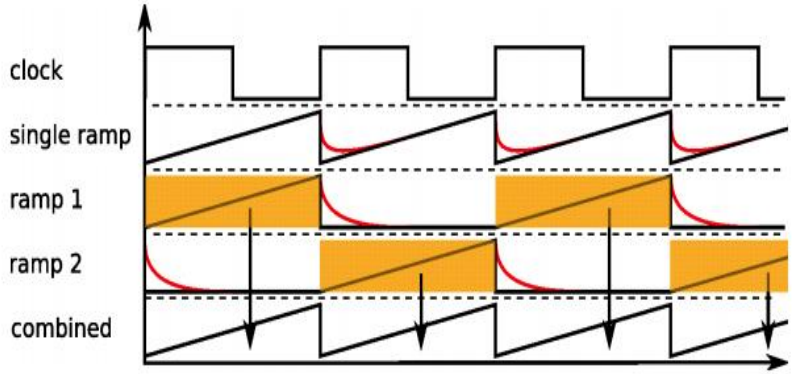


ΔT between calculated and measured

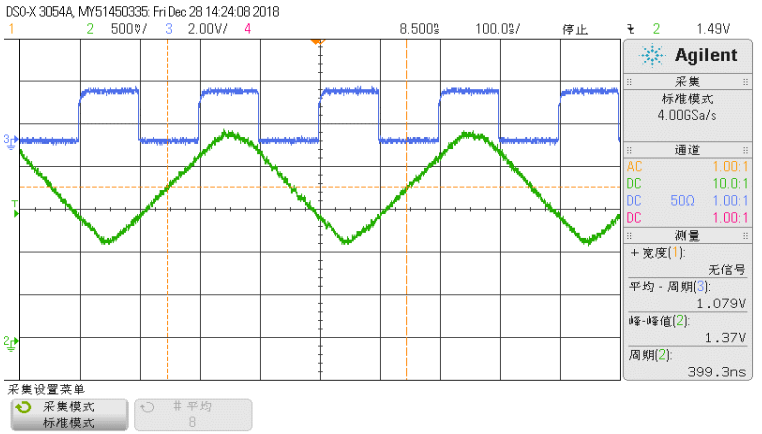
Time measurement

- Channel schematic of SPIROC2E chip
  - High gain
  - Low gain
  - Time measurement





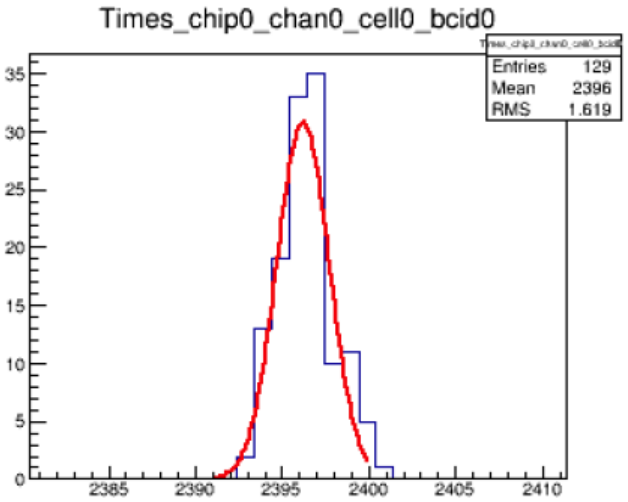
SPIROC2B chip



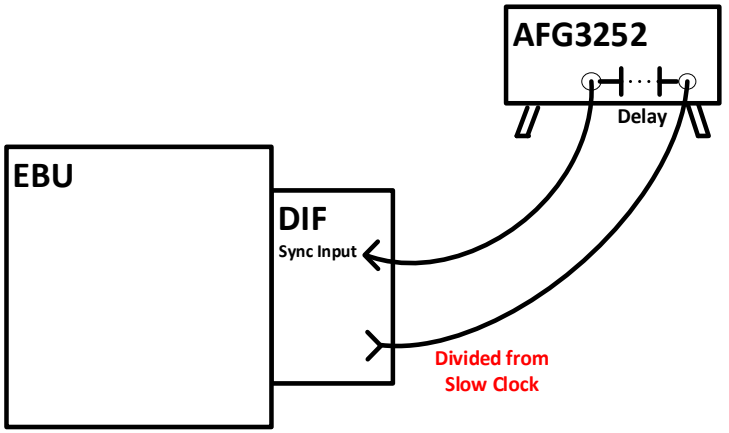
SPIROC2E chip

Time Calibration

- Fan-out signal synchronized with slow clock to AFG3252
- Delay *t* ns then give it to DIF
- Trigger charge injection (Ecalib) and valid it as external trigger



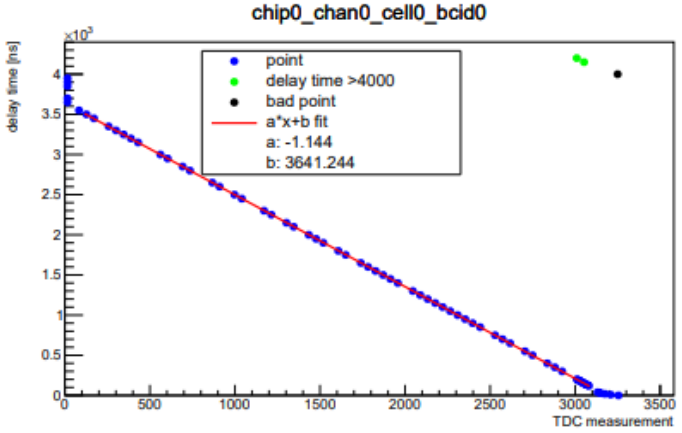
TDC response for a fix delay time

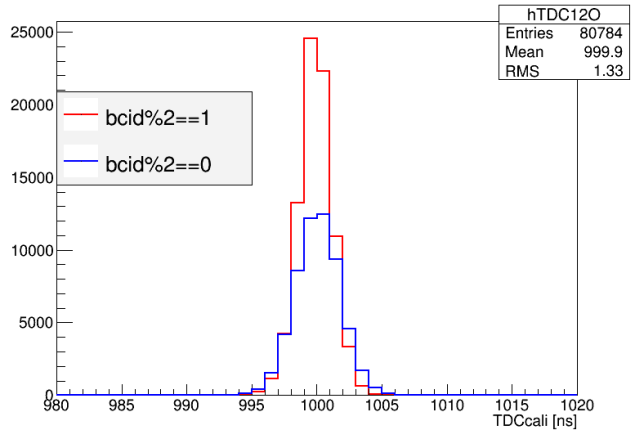


TDC Calibration

Time calibration

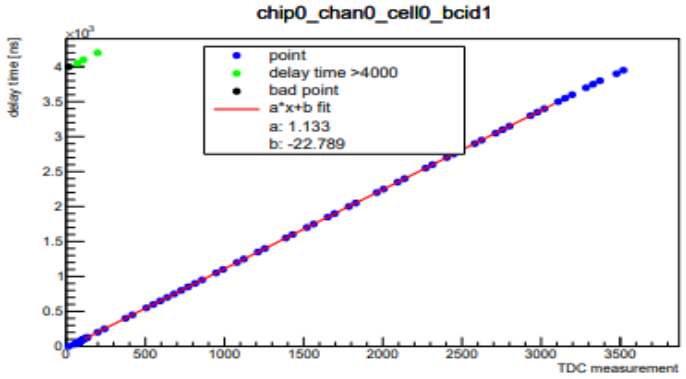
Negative slope ramp



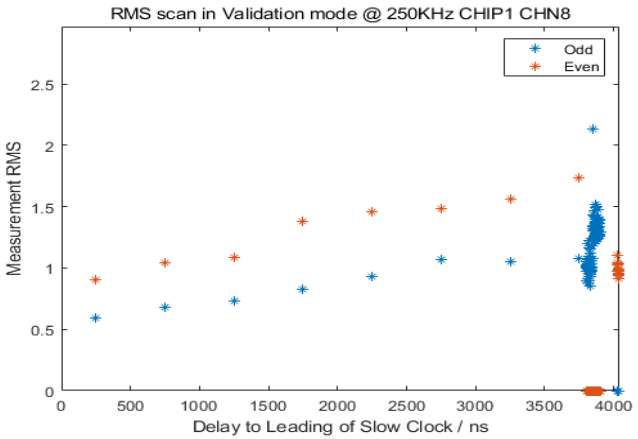


Time resolution at 1000 ns

Positive slope ramp



TDC Channel vs. delay time



Time resolution of TDC