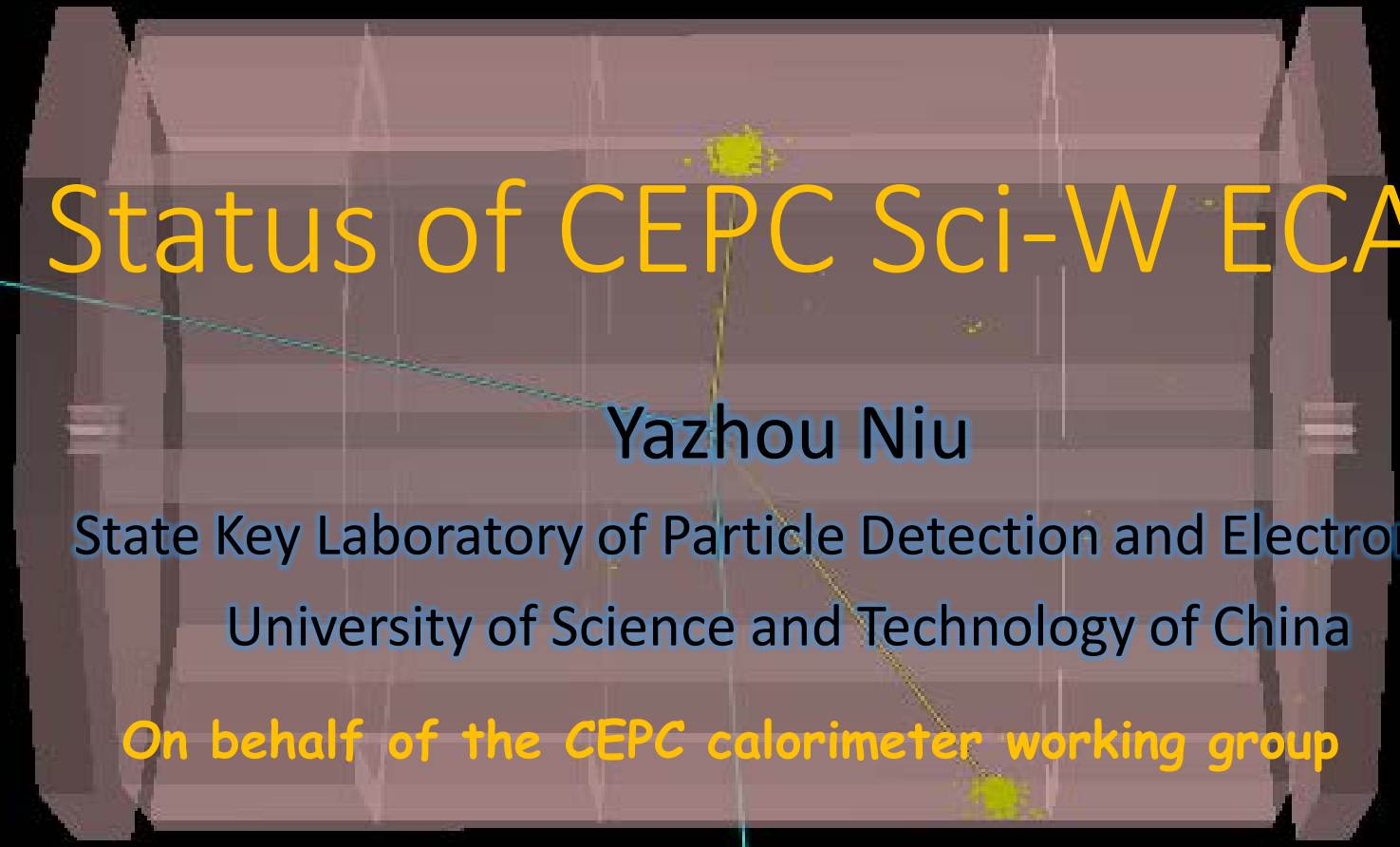
CEPC workshop November 18-20, 2019 at IHEP, Beijing



# Status of CEPC Sci-W ECAL


Yazhou Niu

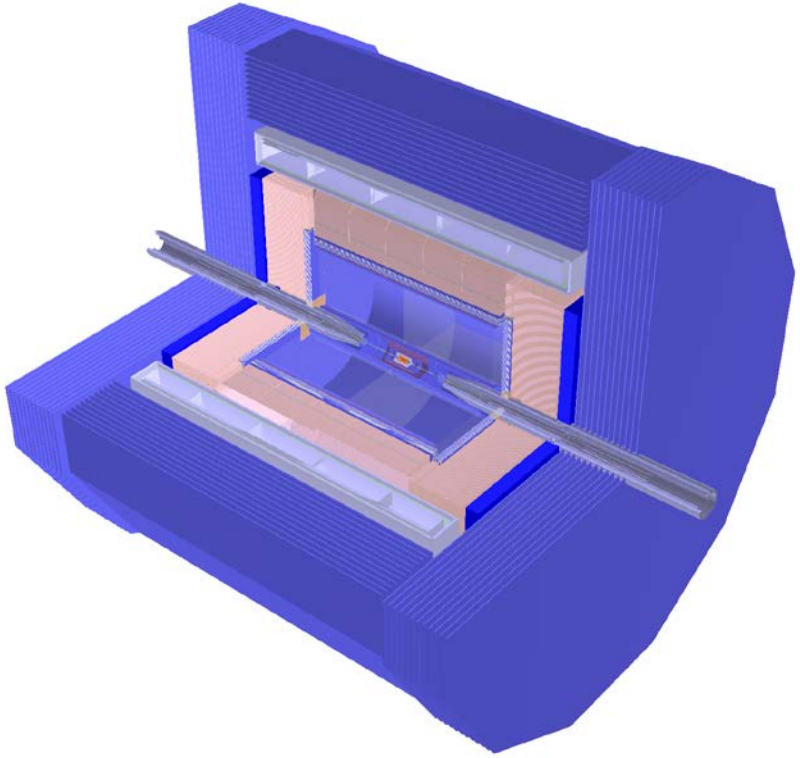
State Key Laboratory of Particle Detection and Electronics,

University of Science and Technology of China

*On behalf of the CEPC calorimeter working group*

# Outline

- Performance requirements, roadmap and overview of ECAL prototype
- ECAL unit optimization and study
  - SiPM study
  - Scintillator strip
  - Readout Electronics
- CEPC Sci-W ECAL prototype progress
- Double-side prototype progress
- Summary



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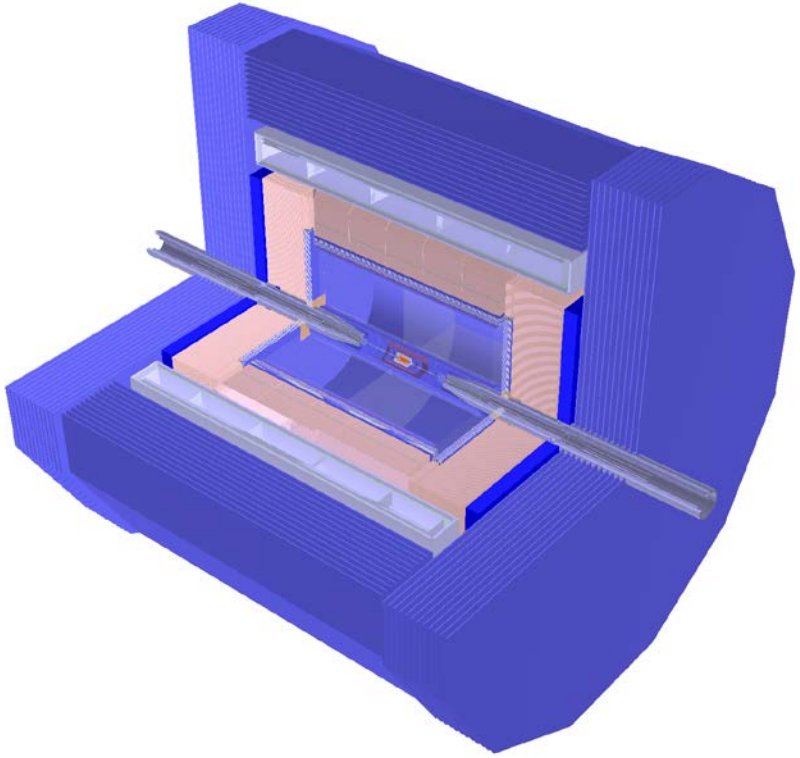
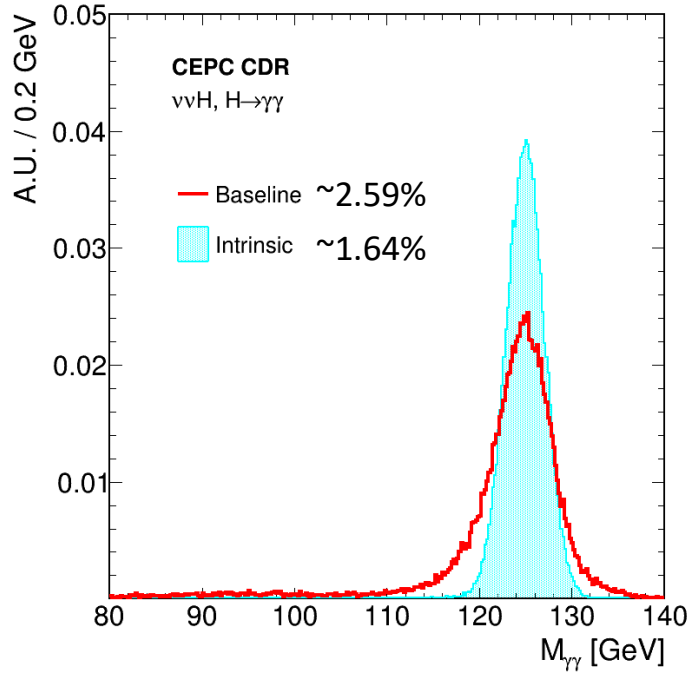


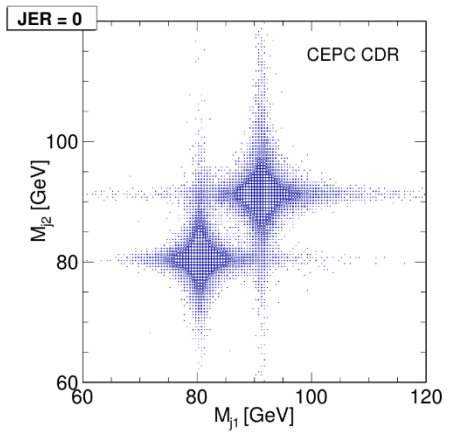
# Performance requirements

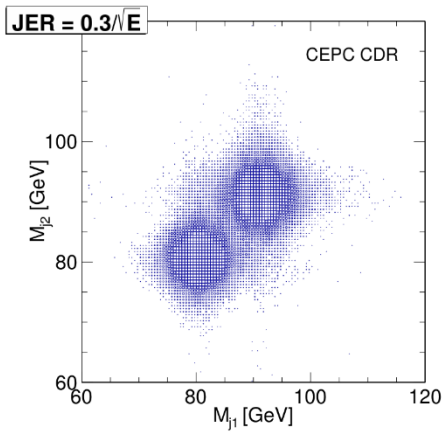
| | | | |
|---|---|---|---|
| $H \to q\bar{q}, WW^*, ZZ^*$ | $\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$ | ECAL<br>HCAL | $\sigma_E^{\mathrm{jet}}/E =$<br>$3 \sim 4\%$ at 100 GeV |
| $H \to \gamma\gamma$ | $\mathrm{BR}(H \to \gamma\gamma)$ | ECAL | $\Delta E/E =$<br>$\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$ |

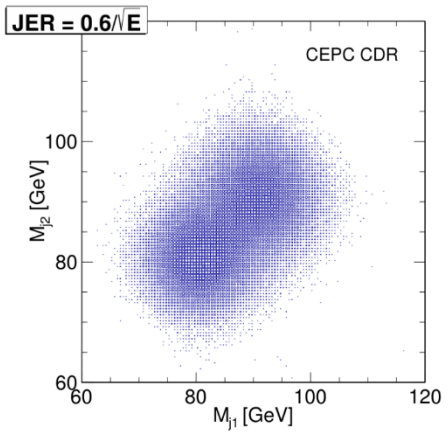



- Energy resolution of γ:
  - $\boldsymbol{\sigma_E/E \approx 16\%/\sqrt{E} \oplus 1\%}$
- Jet energy resolution (combined tracker, ECAL and HCAL)
  - $\boldsymbol{\sigma_E/E \approx (3\%\sim4\%)@100GeV}$

CEPC CDR : http://cepc.ihep.ac.cn/CEPC_CDR_Vol2_Physics-Detector.pdf

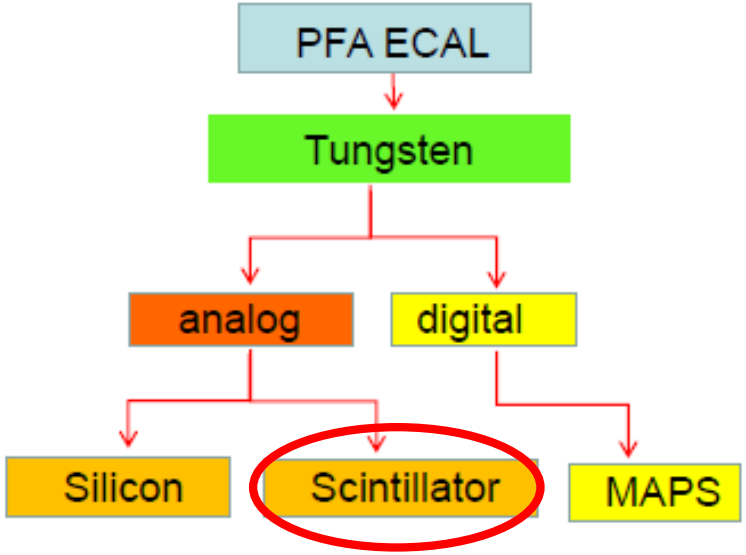



WW→4j and ZZ→4j

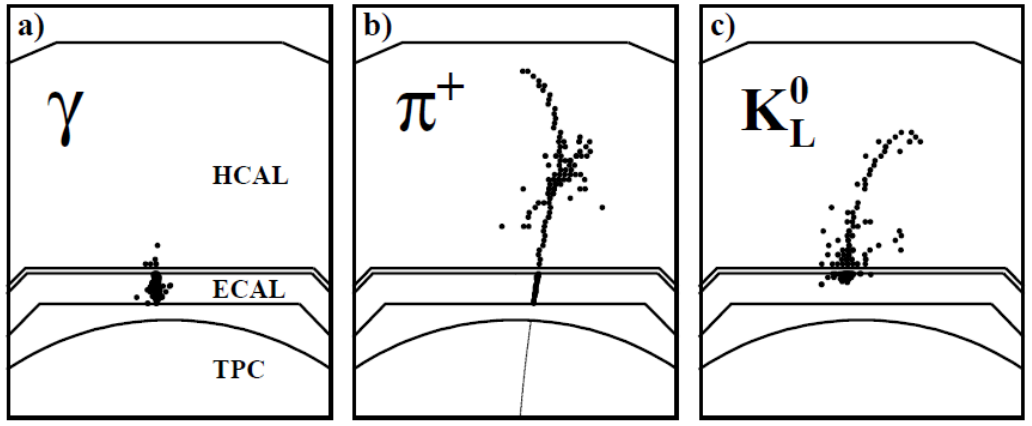
# Roadmap



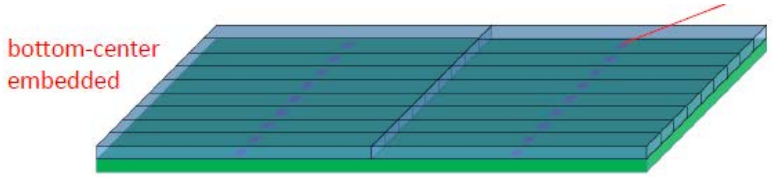

- PFA oriented electromagnetic calorimeter

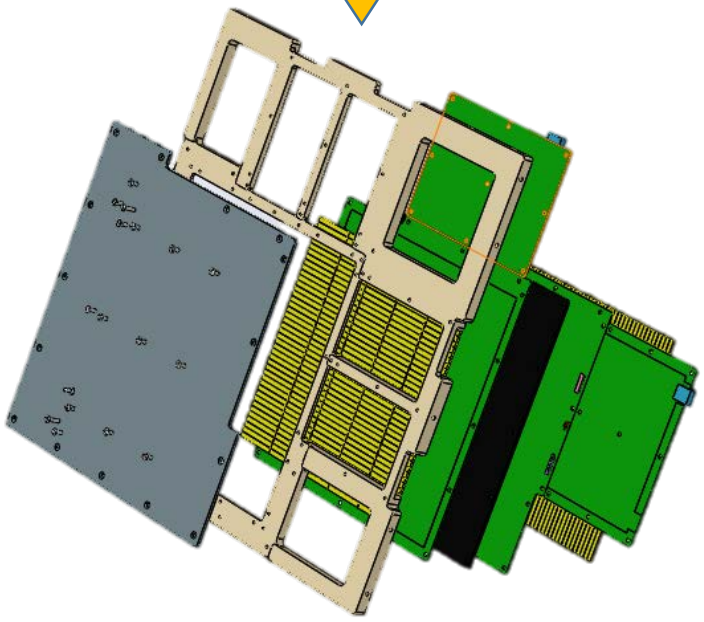
✓ Scintillator-tungsten ECAL

- Sandwich structure
  - Absorber + SD + Electronics
- High granularity
  - $5mm \times 45mm$ scintillator strip
- Larger dynamic ranger
  - Scintillator + SiPM
  - SPIROC Chip

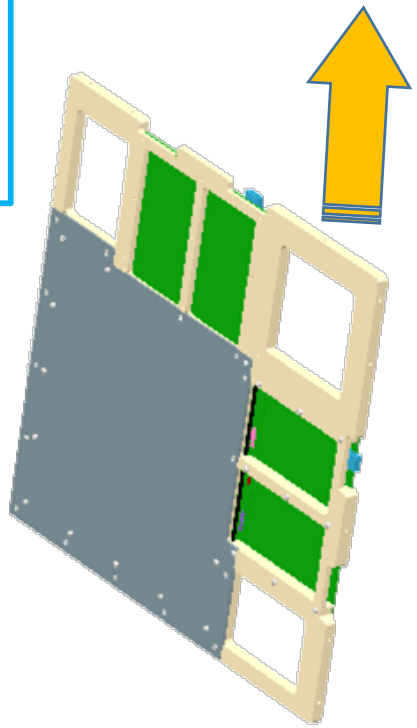


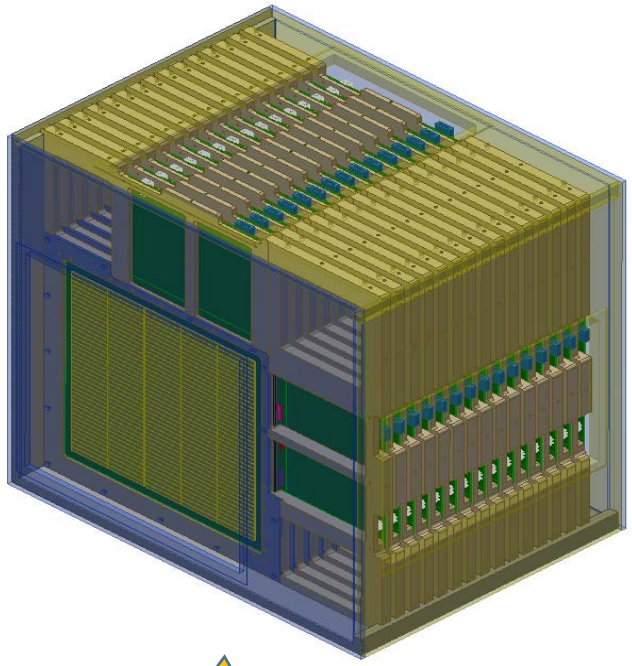
# Overview of ECAL prototype



- 6300 channels
- 30 EBUs + 30 DIFs
- 15 “active layers”
- Full ECAL prototype





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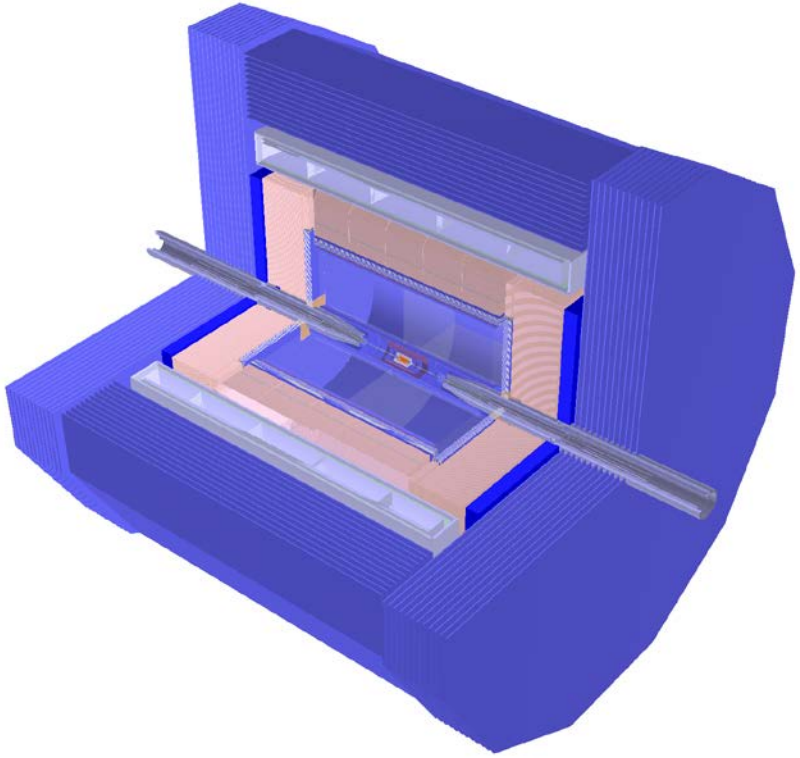
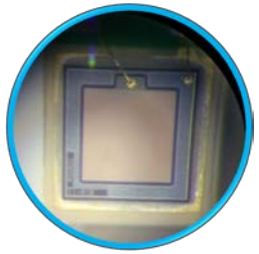
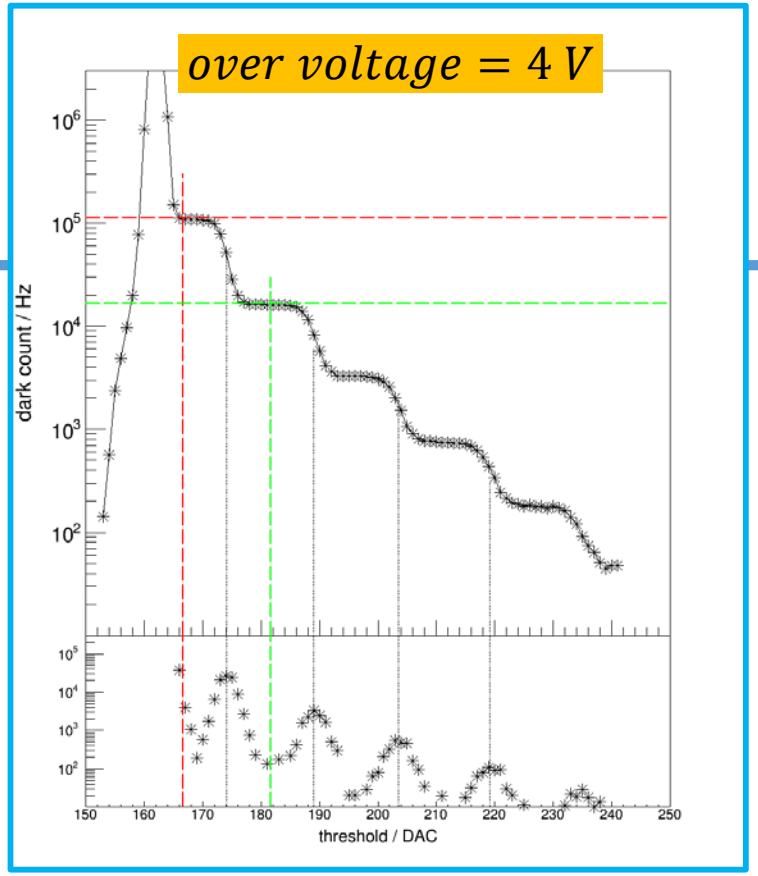


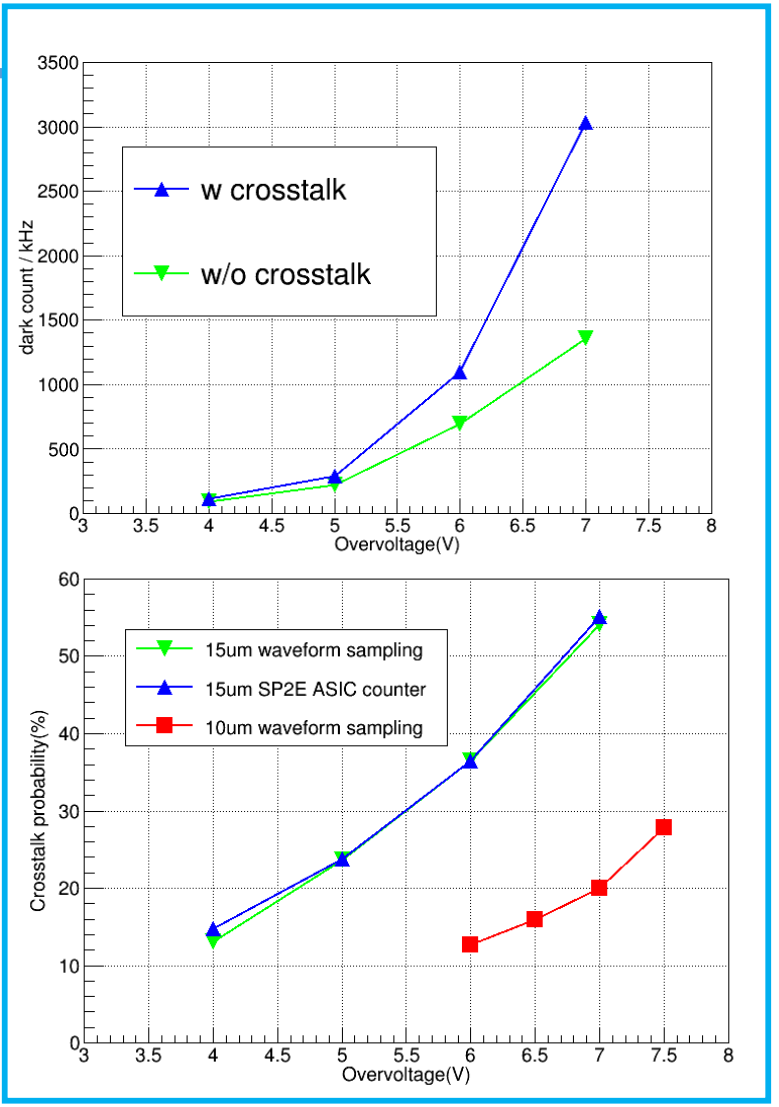
# SiPM study



Hamamatsu S12571-010P
- Area: $1mm \times 1mm$
- Size: $10\mu m$
- Pixels: 10K

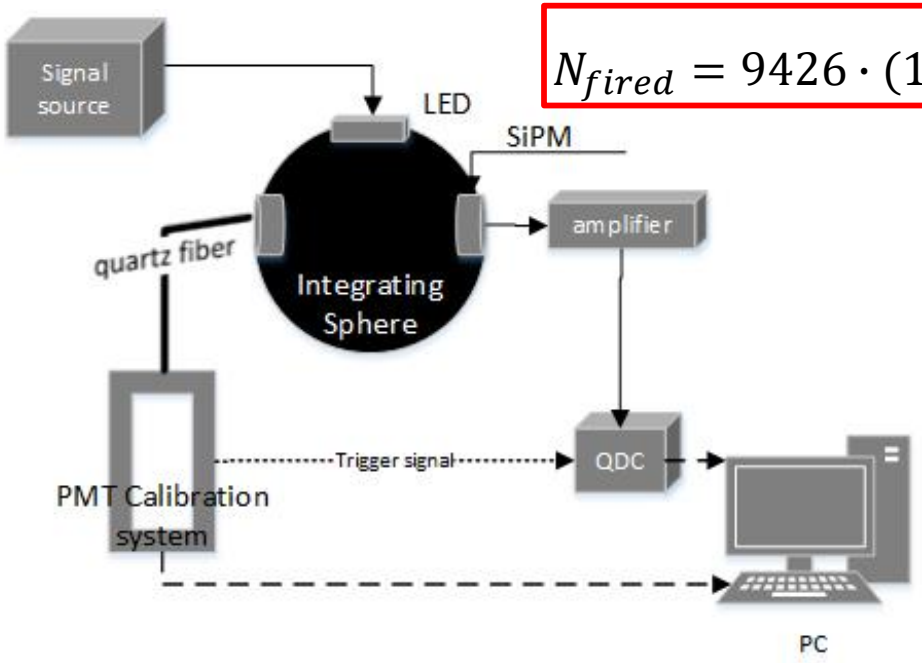



*dark count: >0.5 p.e.
*cross talk: >1.5 p.e.

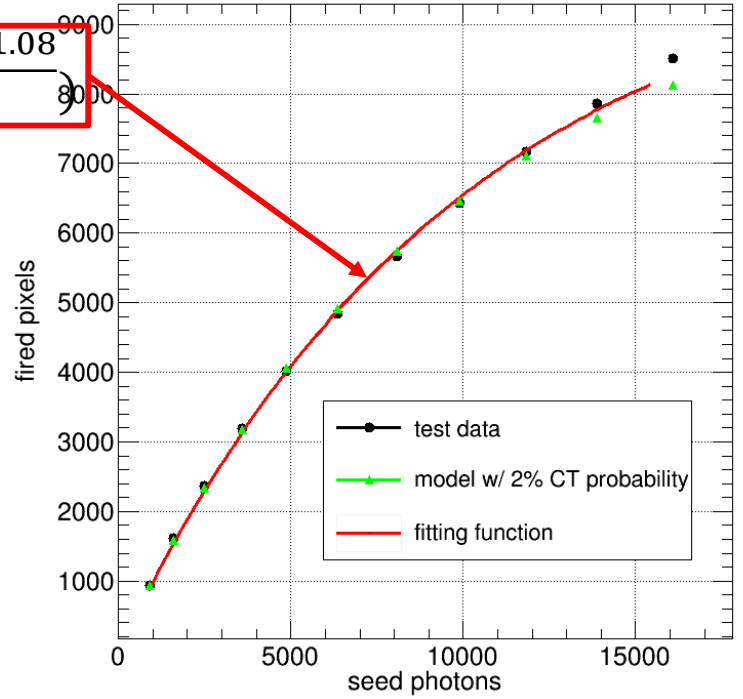



- SiPM always have dark noise and cross talk
- Dark noise rate is ~100kHz on operation voltage
- CT possibility is ~15% for 15um and 8% for 10um
- DNR and CT both increase rapidly with over voltage

# SiPM saturation study



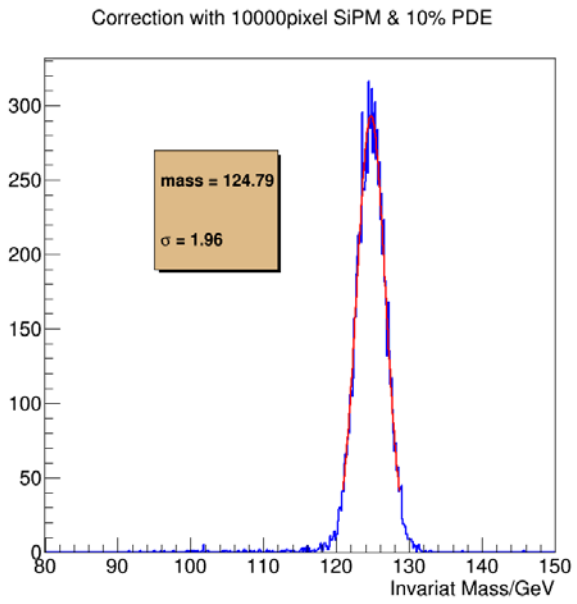

$$N_{fired} = 9426 \cdot (1 - e^{\frac{-N_{photon} \times 1.08}{9426}})$$

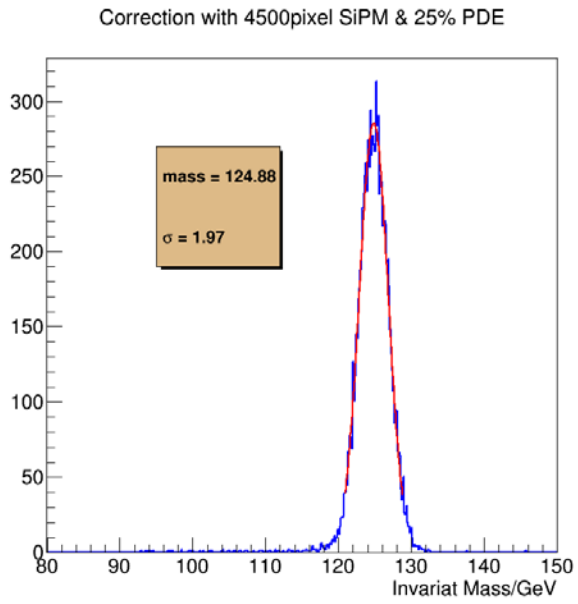


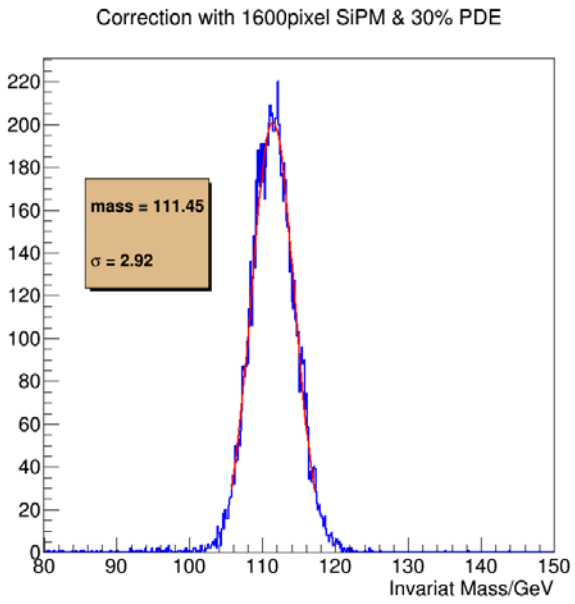

- SiPM response would arise saturation when incident photon raise
- SiPM saturation can be described very well with the function and validated by test data
- After correction, SiPM dynamic range can up to 15,000 photons within 3% error

# SiPM saturation correct

$Higgs \rightarrow \gamma\gamma$



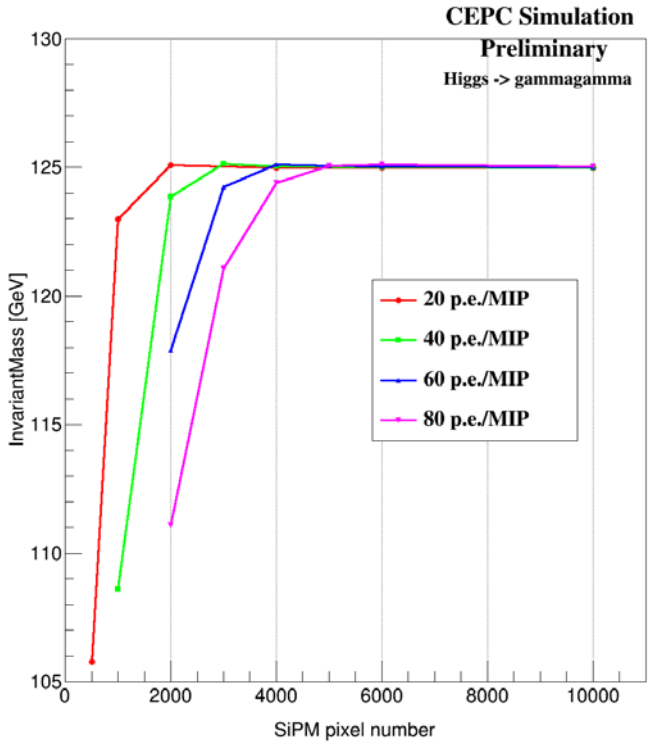

| Pixel | 10000 | 4500 | 1600 |
|---|---|---|---|
| MIP LY / p.e. | 20 | 50 | 60 |
| PDE / % | 10 | 25 | 30 |
| Mean / GeV | 124.79 | 124.88 | 111.45 |
| $\sigma/Mean$ | 1.57% | 1.58% | 2.62% |

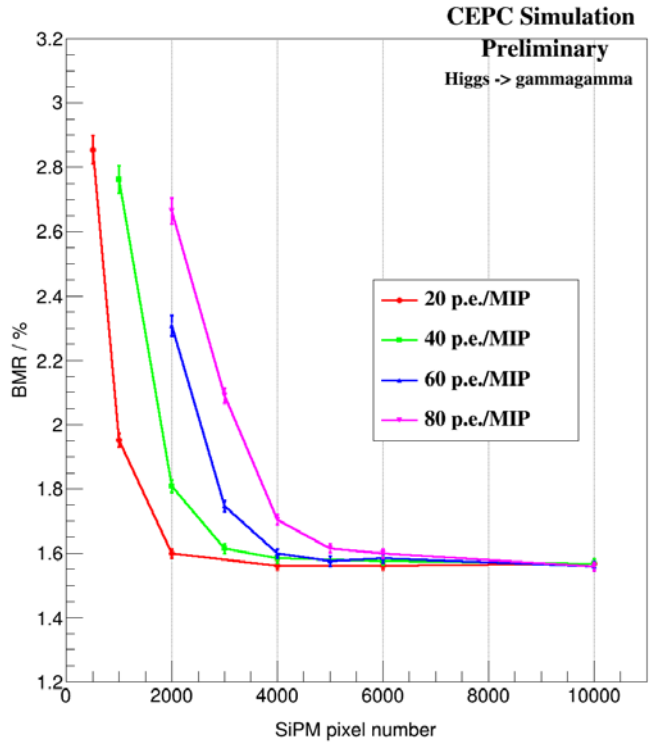
- SiPM saturation effect can be corrected in very large range

# SiPM saturation correct

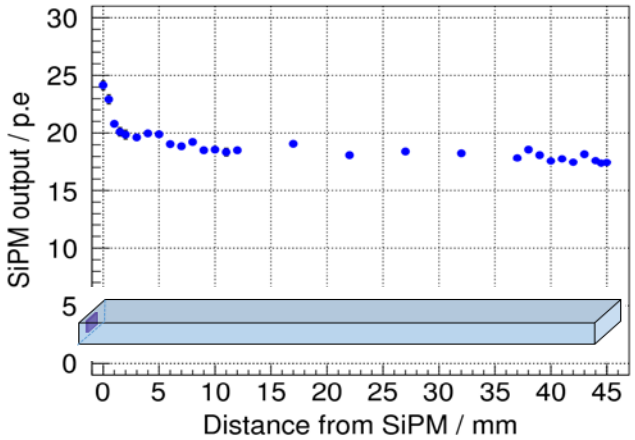
$Higgs \rightarrow \gamma\gamma$

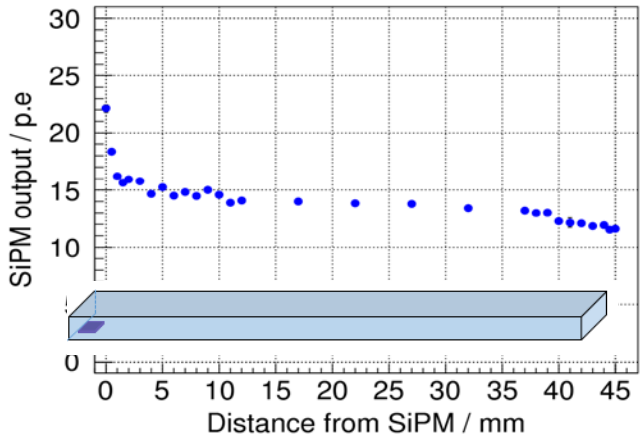
- SiPM oversaturation correction would not operate
- 20 p.e. / MIP require no less than 4000 pixels number
- 10K pixel can meet dynamic range requirement for CEPC-ECAL

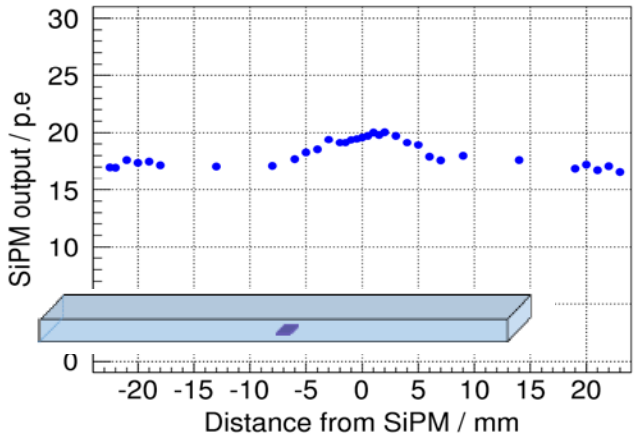


# Scintillator strips study and optimization



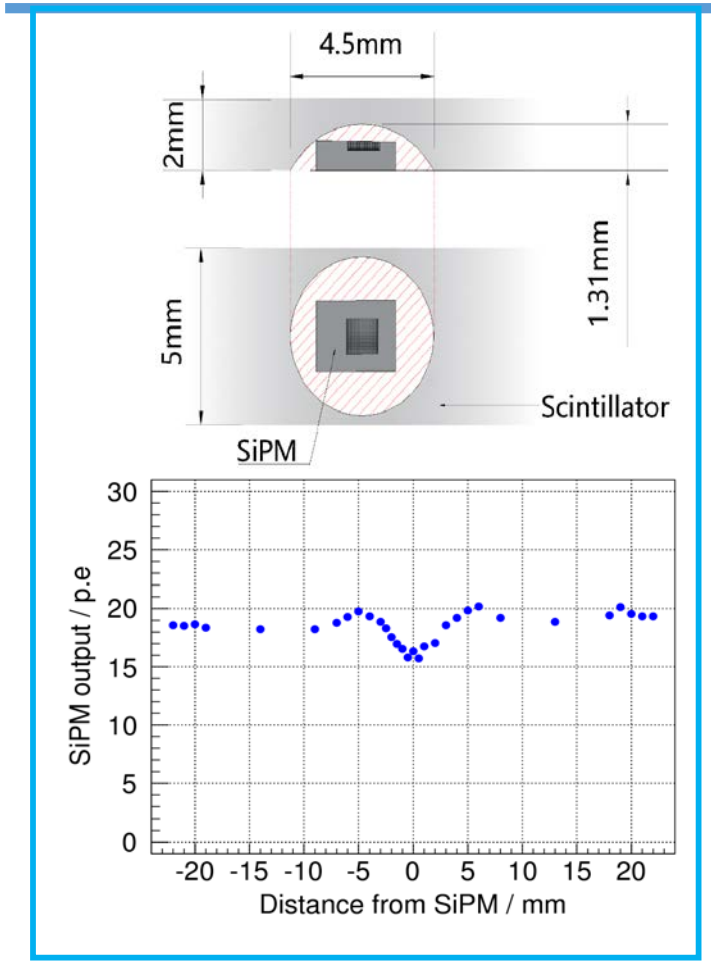

> Three classes coupling mode i.e. side-end, bottom-end and bottom-center

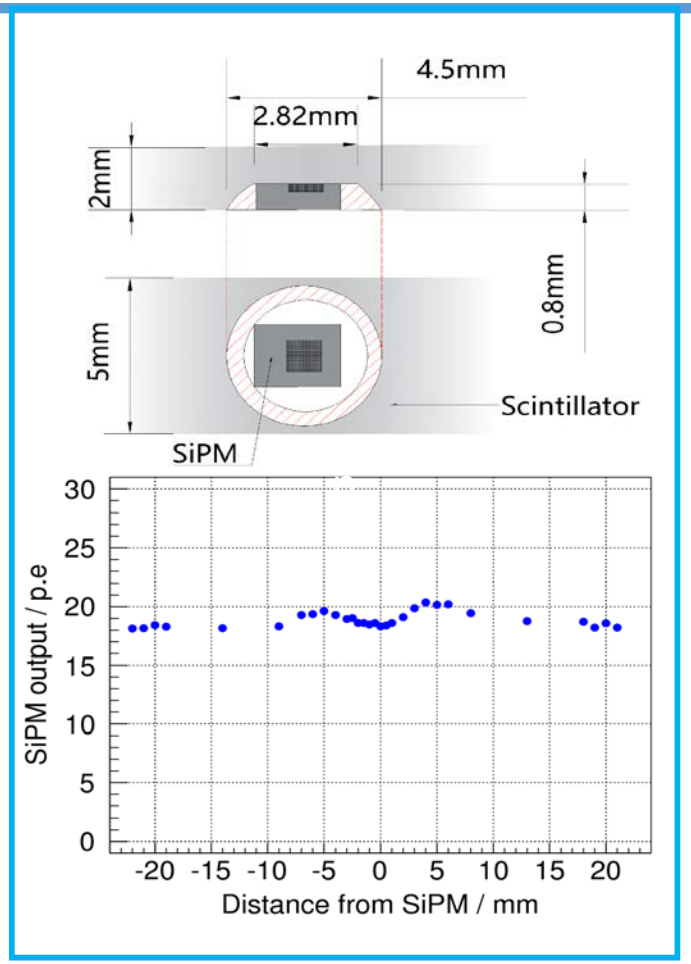
> Light outputs along the length of the scintillator strip is non-uniformity, degrades the energy resolution

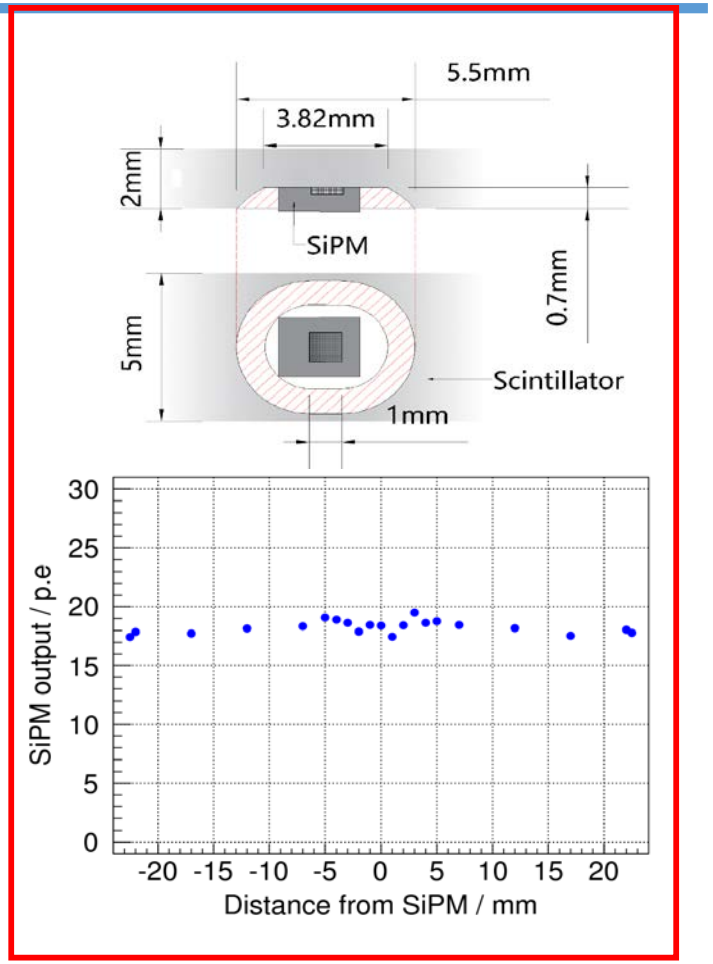
> Bottom-center coupling have the minimum non-uniformity

- Avoiding the dead area between scintillators introducing by SiPMs
- Simplifying scintillators assembling process
- Enabling to extend the SiPM area with more pixels

# Scintillator strips study and optimization

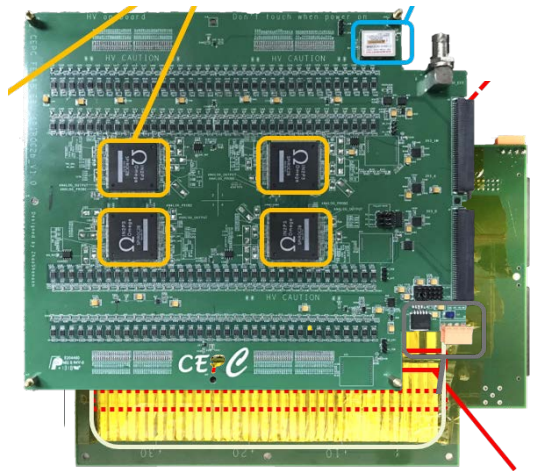


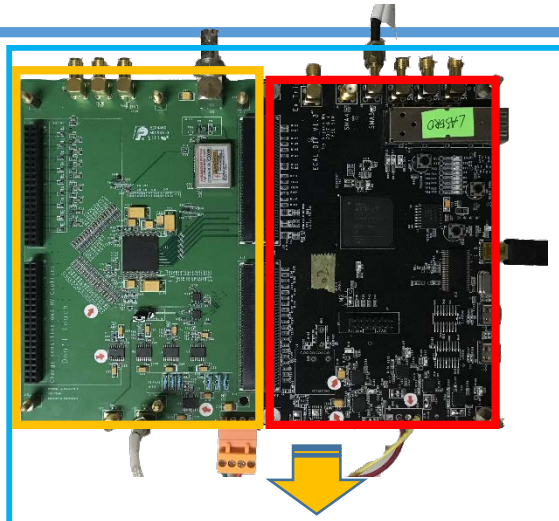



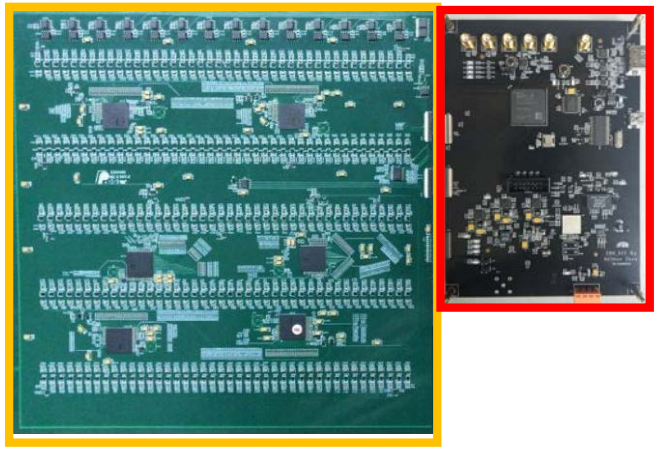

- The non-uniformity of scintillator unit with such runway-shaped dimple can reach 4%

# Electronics study

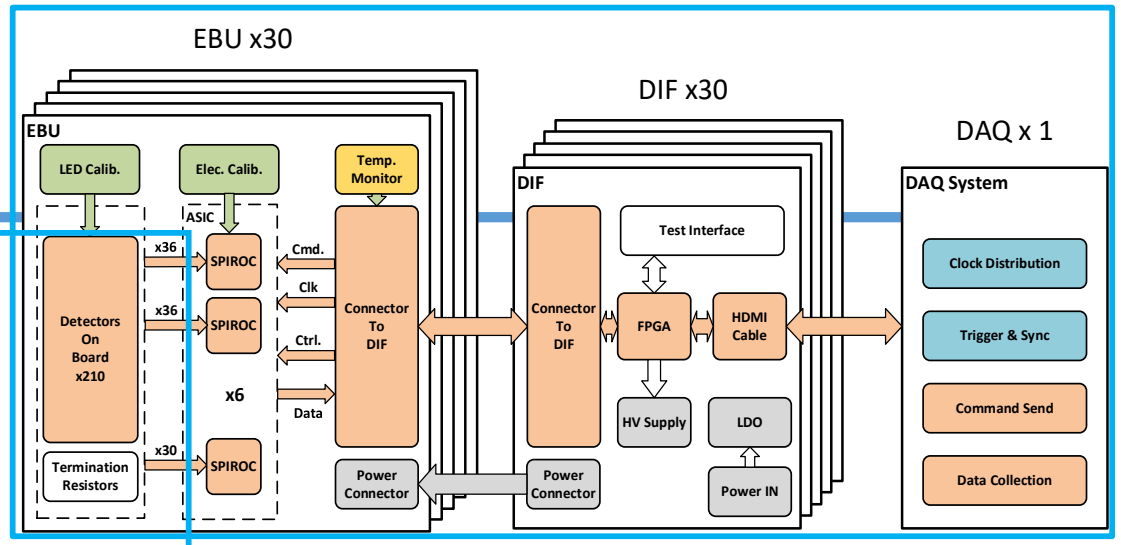


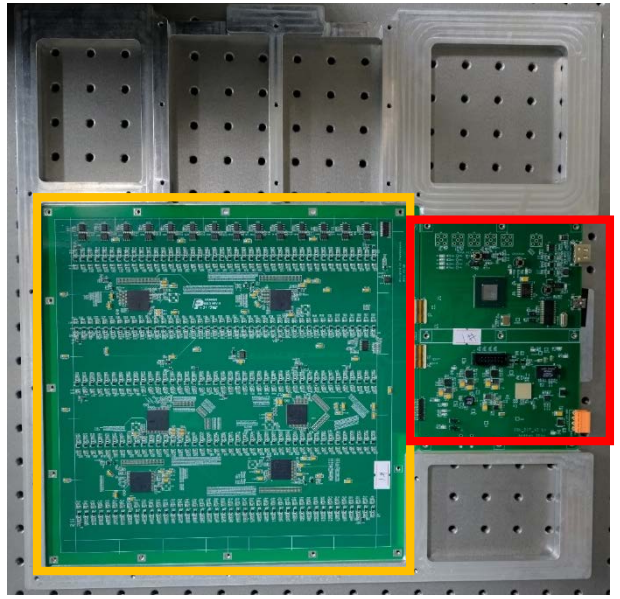
EBU SP2b 144channels





EBU SP2e 210channels



EBU SP2e technological board

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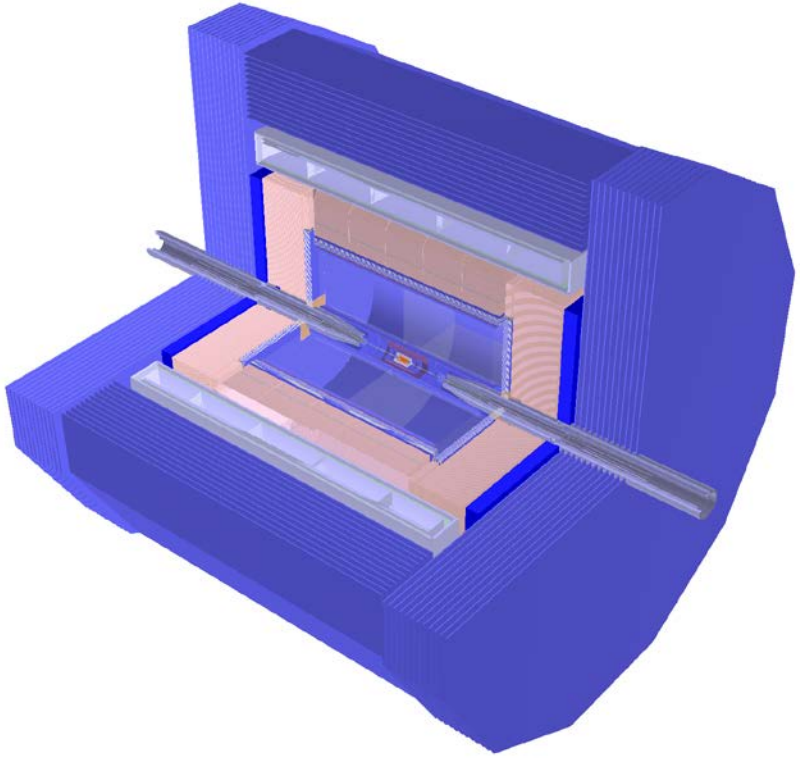


# EBU2e technological board

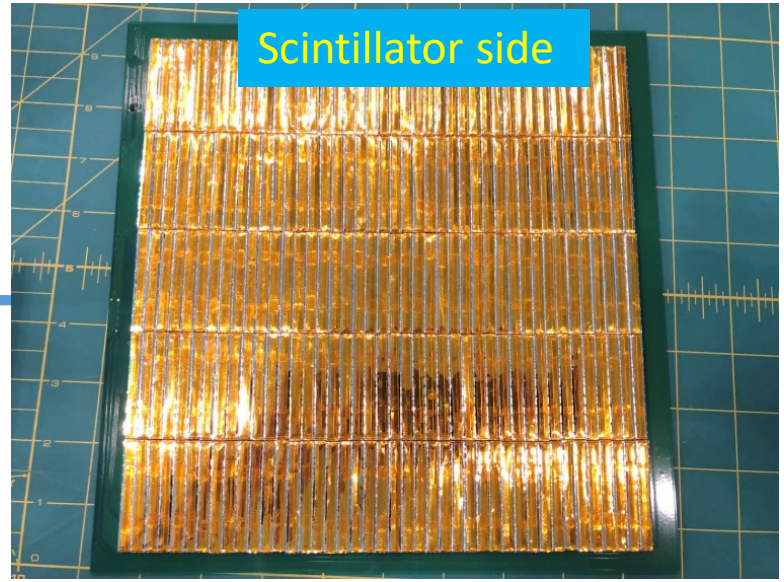
> 210 channels readout with 6 SP2E chips divided into 5 rows and 42 columns

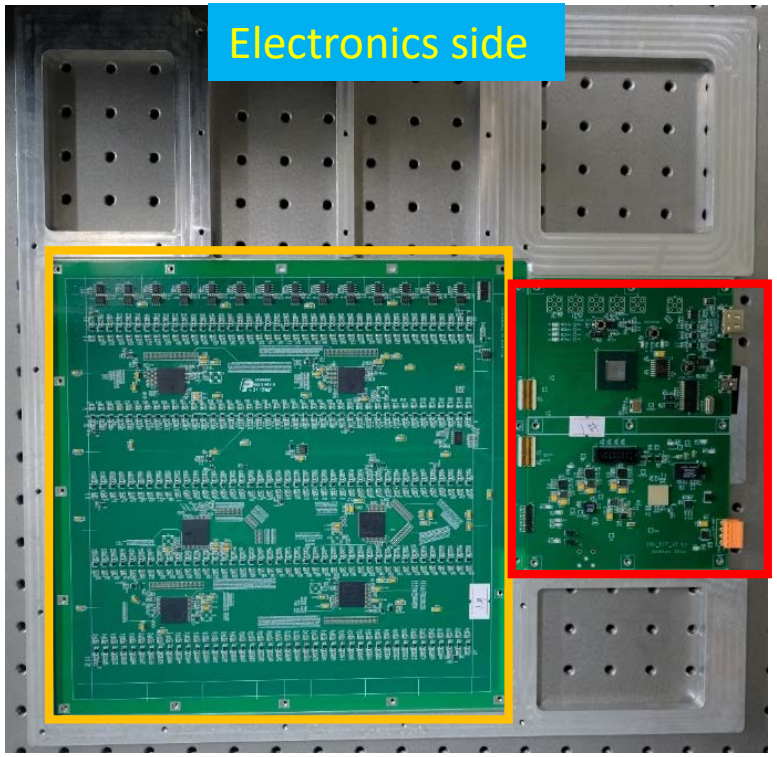
> Using 10um S12571-010P / 15um S12571-015P SiPMs, produce by Hamamatsu

> Total thickness is controlled under 6mm ($< 1mm$ deviation) excluding DIF

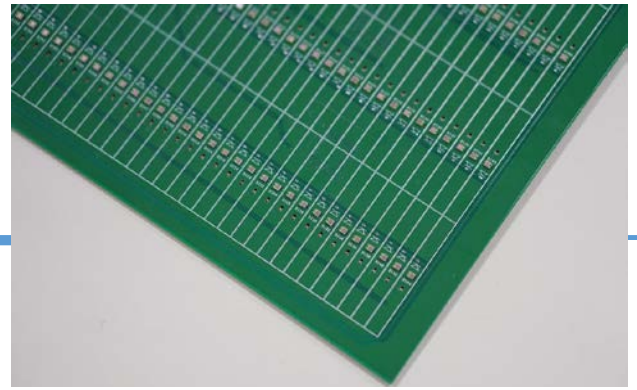
> DAC calibration and SiPM operation voltage adjustment realized

> LED calibration and temperature monitor system can available



# LED calibration

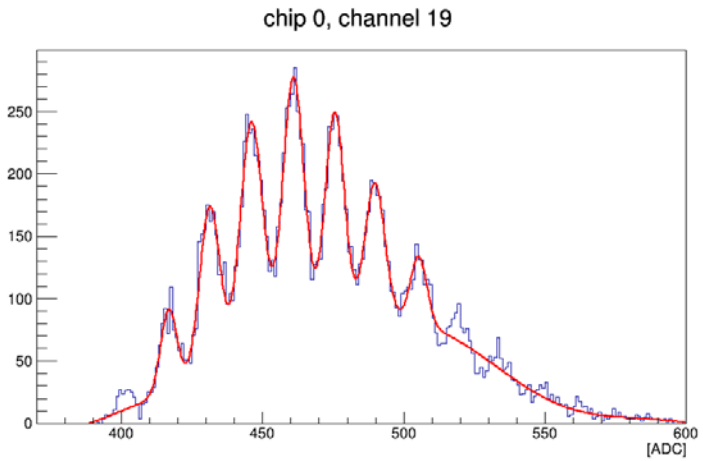


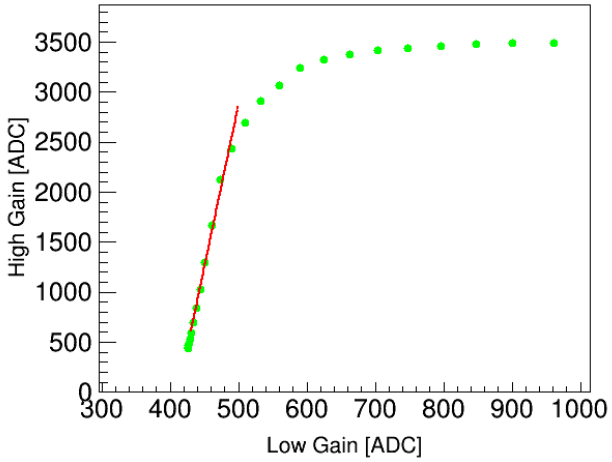
> Check all channels SiPM response

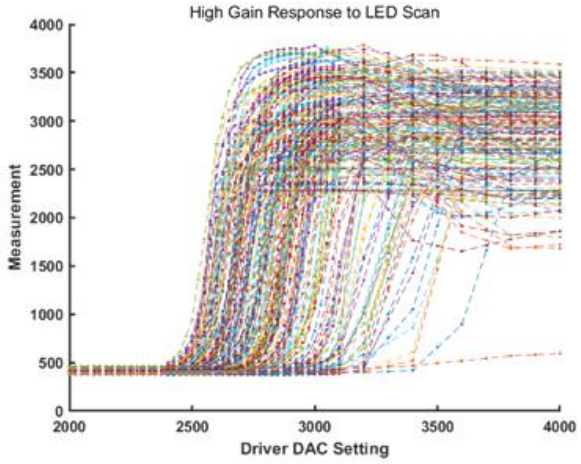
> Calibration SiPM gain by single photon electron spectrum

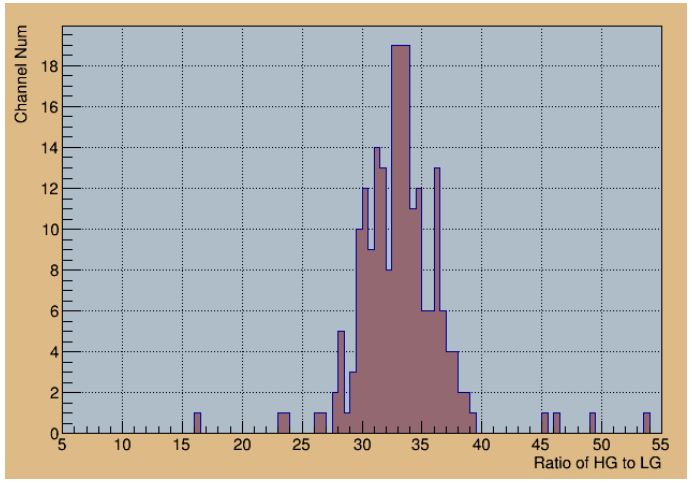
> Calibration the ratios of high gain versus low gain

> Define linearity range of High gain mode

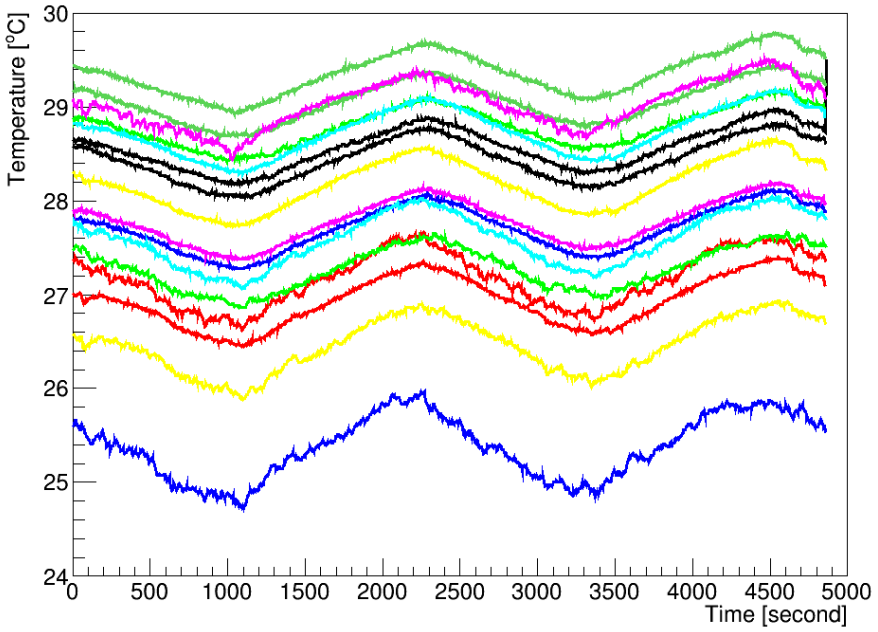


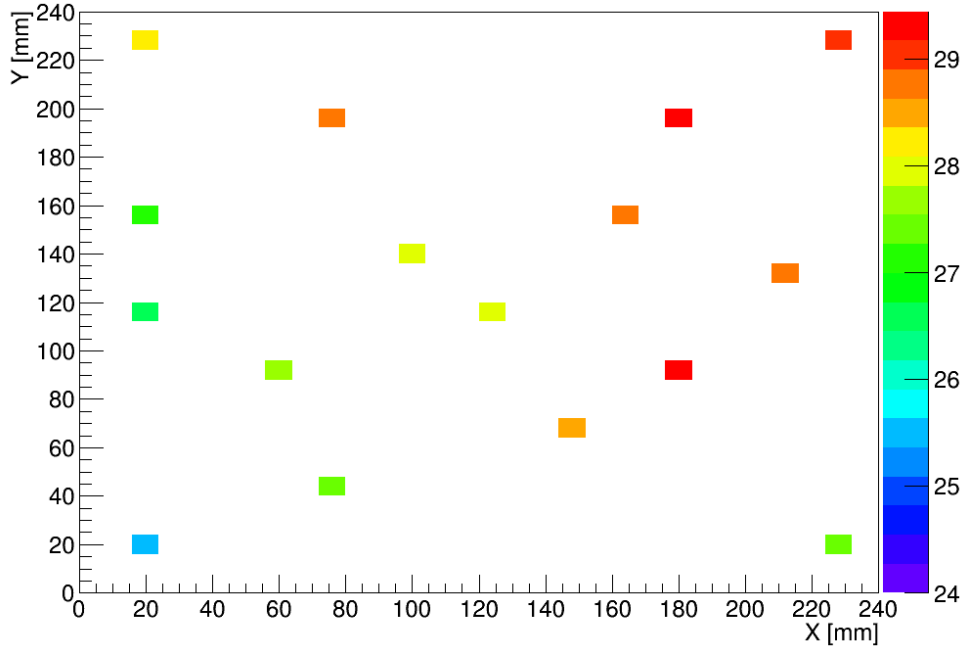



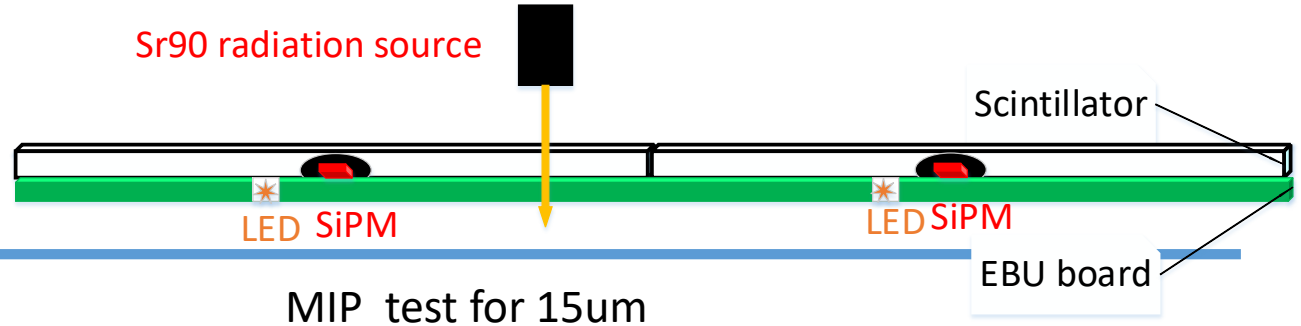
# Temperature monitor



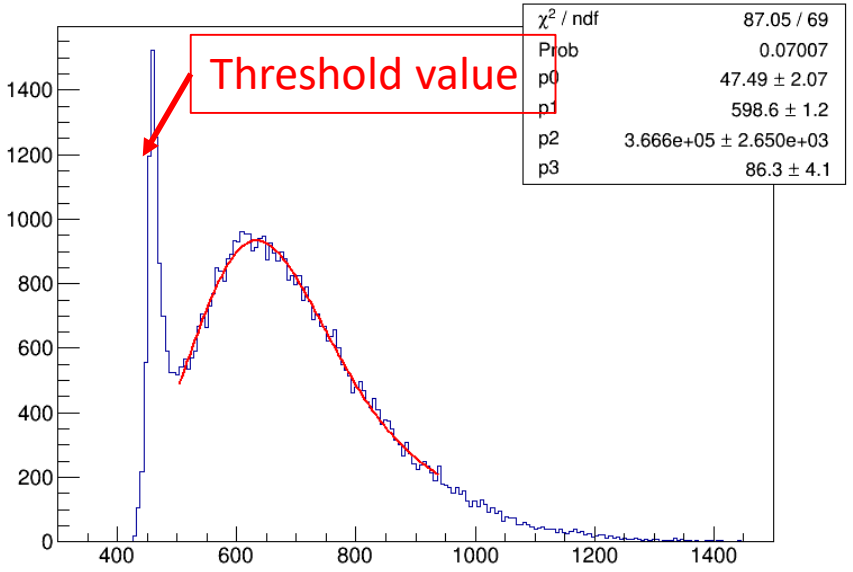




- 16 temperature sensor distribution on the EBU
- Calibration of these sensors: to be done
- $0.1\ {}^{o}C$ precision can achieved
- Temperature feedback and DAC compensation: to be implemented

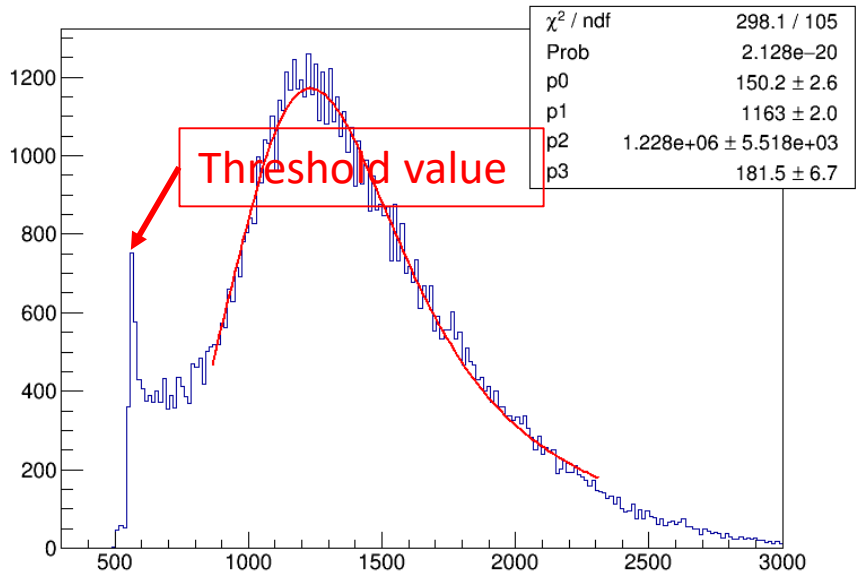
# MIP test with Sr90




MIP test for 10um




MIP test for 15um



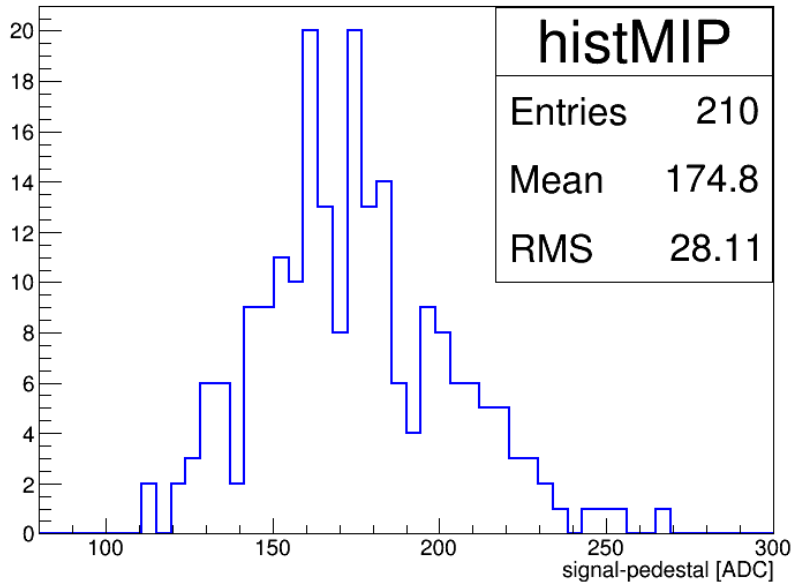

- 25ns shaping time for 10um and 15um SiPM
- There are using self-trigger(auto-trigger) with 16 memory cell
- SiPM work on operation voltage
- MIP fit: $landau \otimes gaus$ with range $(\frac{peak}{2}, \frac{peak}{4.5})$

Channel Level

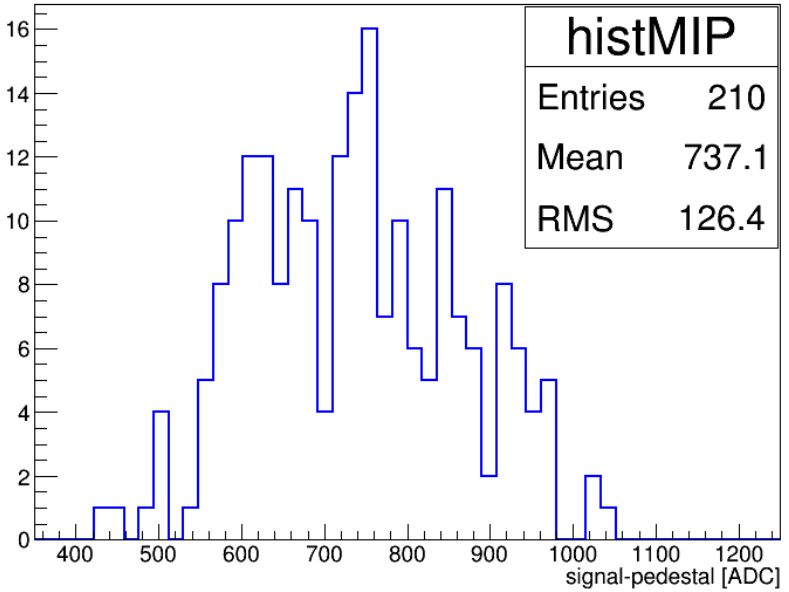
# MIP test with Sr90

- Both 10um and 15um distinguish MIP signal : 100%
  - > MIP variation:  RMS / MIP MPV ~ 16% for 10um and  ~ 17% for 15um
  - > Signal over Noise Ratio:  MIP MPV / Pedestal RMS ~ 35 for 10um and ~ 135 for 15um
  - > Negligible variation between 16 memory cell

**MIP test for 10um EBU**



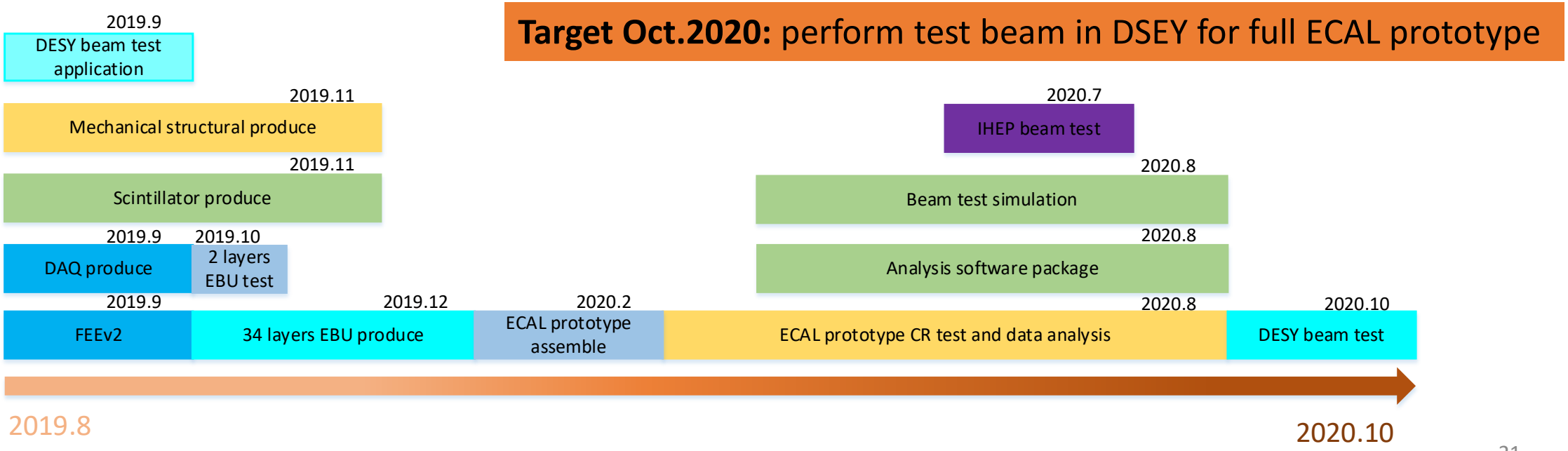

**MIP test for 15um EBU**



# Status and schedule

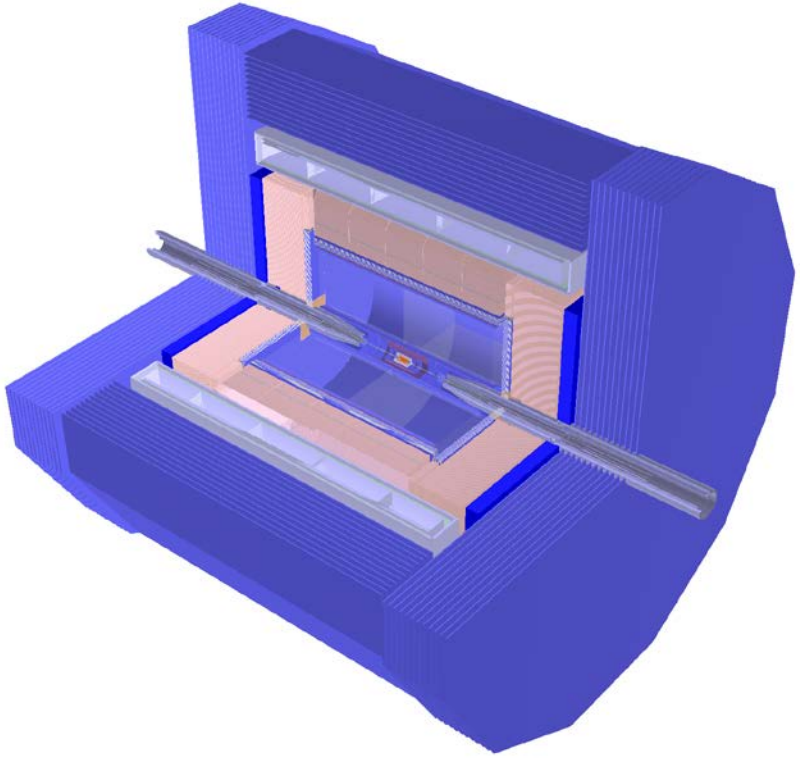
- ✓ Two layers EBU prototype produce and test
- ✓ DAQ system produce and commission with two layers EBU
- ✓ Mechanical structure design and single layer produce
- ✓ SiPMs and scintillators study and purchase

**Target Oct.2020:** perform test beam in DSEY for full ECAL prototype



# Outline

- Performance requirements, roadmap and overview of ECAL prototype
- ECAL unit optimization and study
  - SiPM study
  - Scintillator strip
  - Readout Electronics
- CEPC Sci-W ECAL prototype progress
- Double-side prototype progress
- Summary

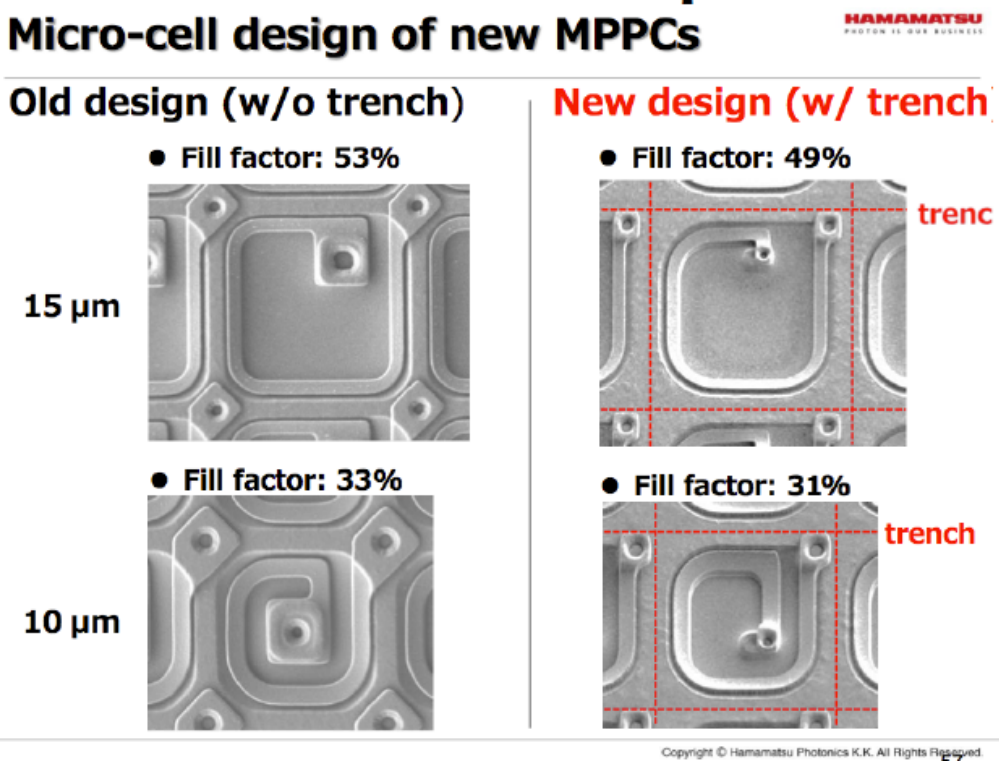


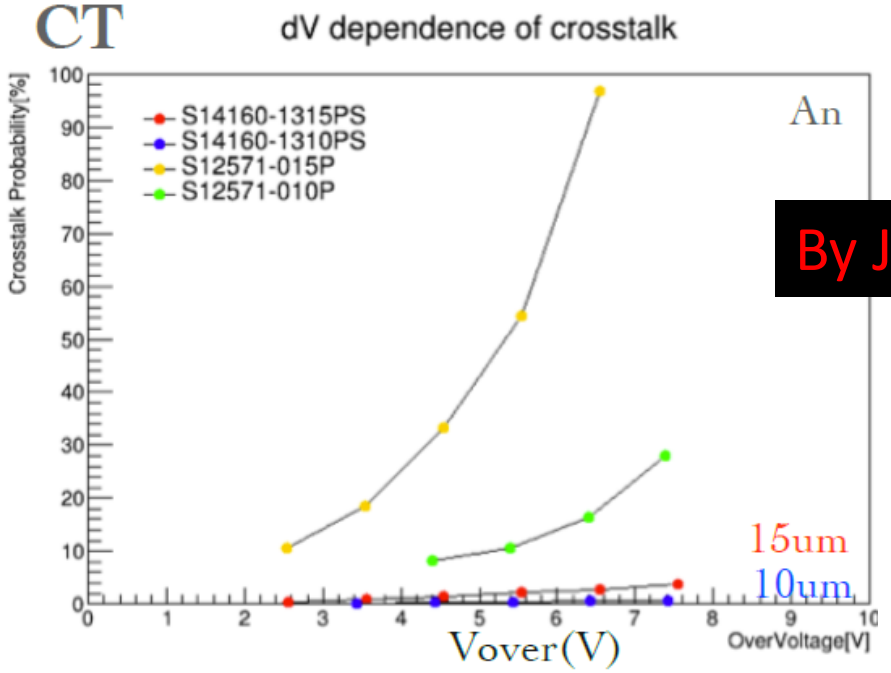
# Additional Introduction

- Two efforts on Sci-W ECAL
  - > Chinese group for CEPC
  - > Japanese group for ILC (ILD)
- Collaboration between two efforts and Joint studies  together
  - > Monthly meeting
  - > Optimization of sensitive unit (scintillator & SiPM)
  - > A technological Sci-W ECAL prototype --- Chinese group
  - > Two layers double-side readout prototype --- Japanese group

# photo-sensor MPPC

- new sensors with trench to reduce cross talk : S14160 rom Hamamatsu
- 10 & 15 um pitch



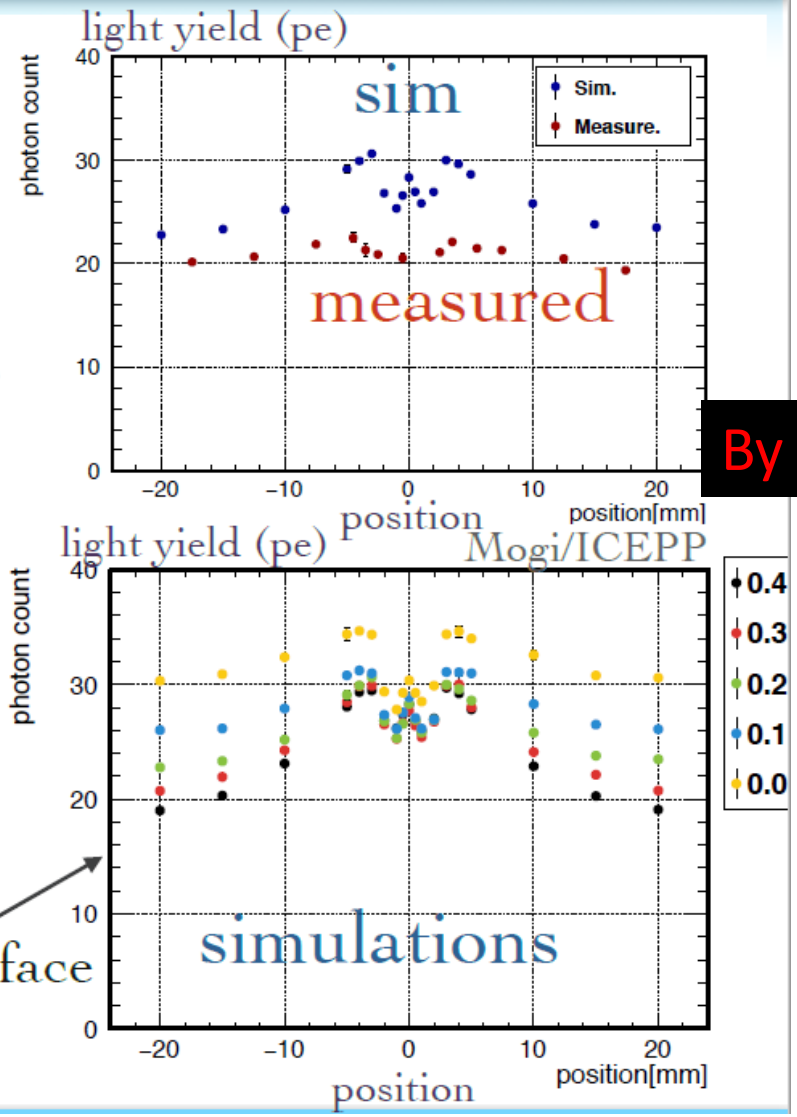

By Japanese group

cross talk reduced

CT15um>CT10um ?

# strip with Center Hole

- center hole/dimple is tested
- compared with G4-light simulation
- still many parameters must be tuned to get good agreement



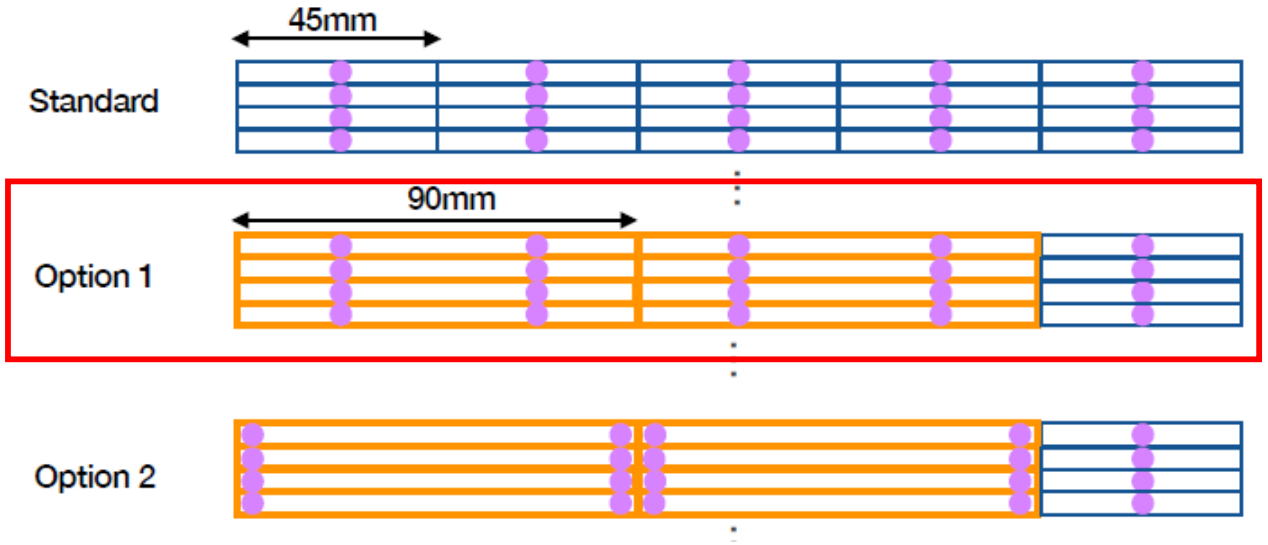

By Japanese group

diffusion rate at scintillator surface

# Detection Layer with Double-Readout

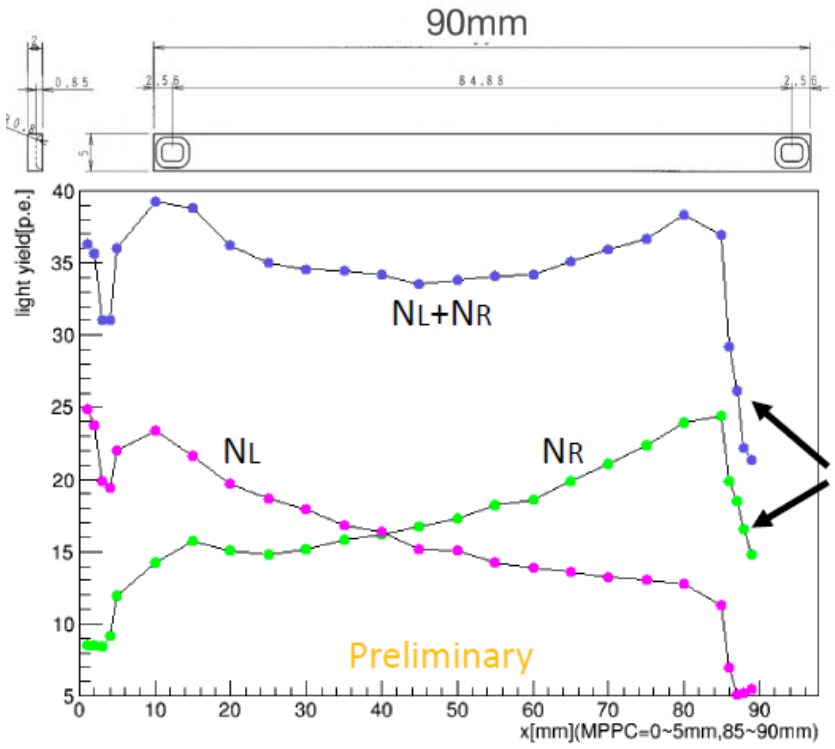
- Suppress random hit by taking coincidence
- Possible to reconstruct position using charge or timing information from two side SiPM
- Strip still operational in case one of the SiPM readouts is dead

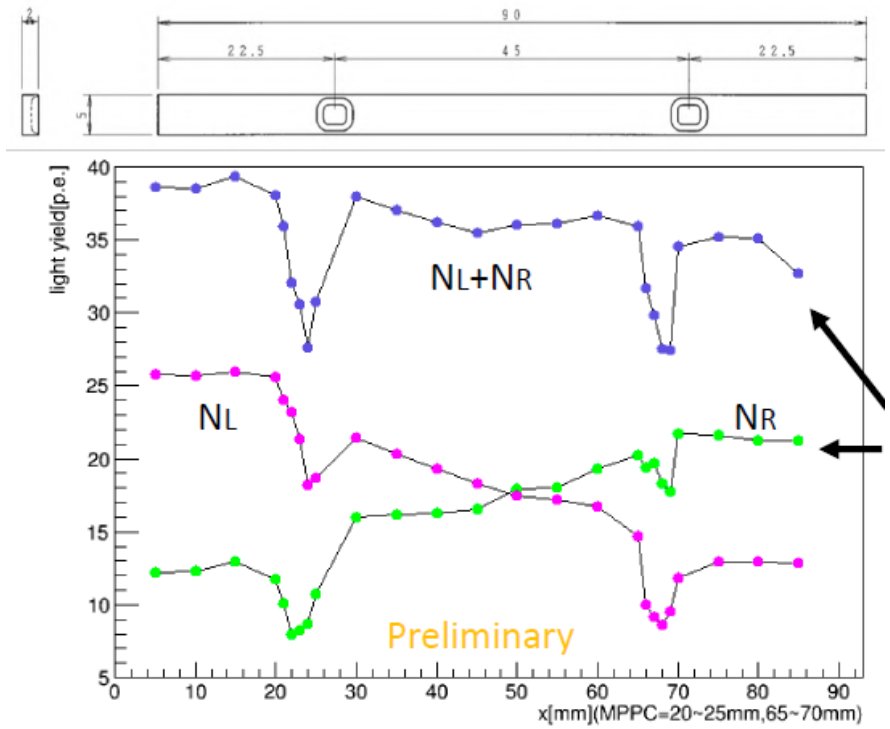
• **Coincidence can be tested in offline analysis**



# Detection Layer with Double-Readout

- Two configuration 90mm strips for double readout have been tested
- Work more or less as expected, but need more studies




Dimple shape is not same with ECAL prototype

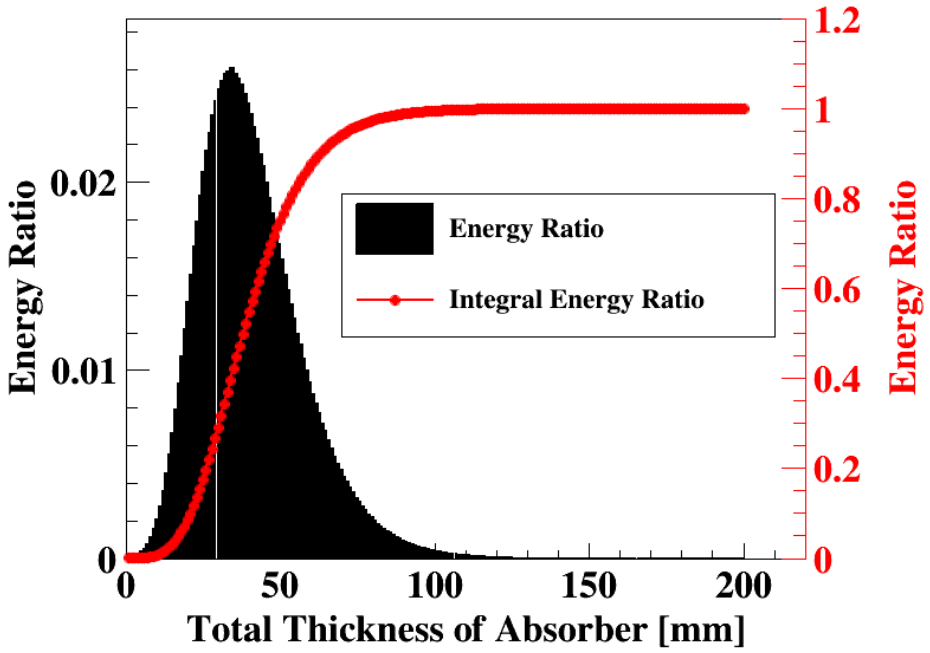
# Summary

- Technological Sci-W ECAL prototype
  - > Scintillator and SiPM joint study by Chinese and Japanese group
  - > Two layers EBU 100% channels MIP test successfully
  - > DAQ commission with two layers EBU will implement of late
  - > 30 layers EBU will be produced by end-December for full prototype
- Double-side readout prototype
  - > Two configuration for double-side readout have been test
  - > Two layers prototype will be produced based on the standard EBU

- Currently, everything is going in the right direction

# Backup

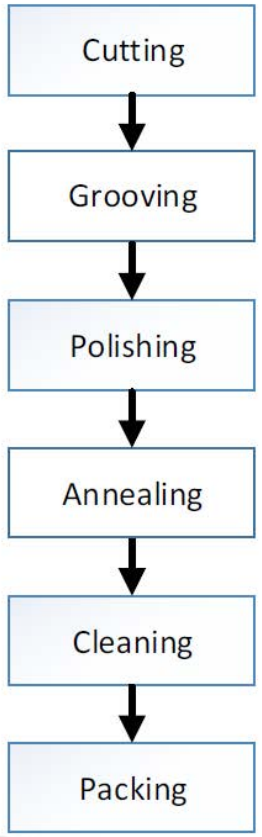
# The thickness of absorber

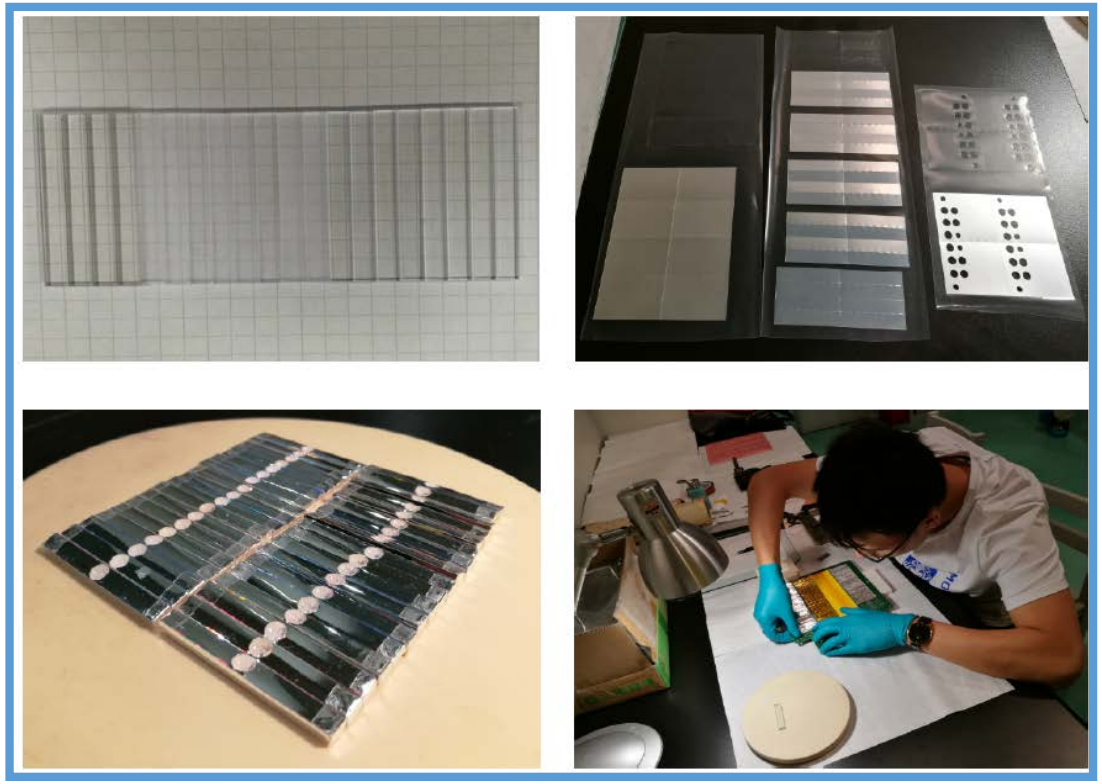


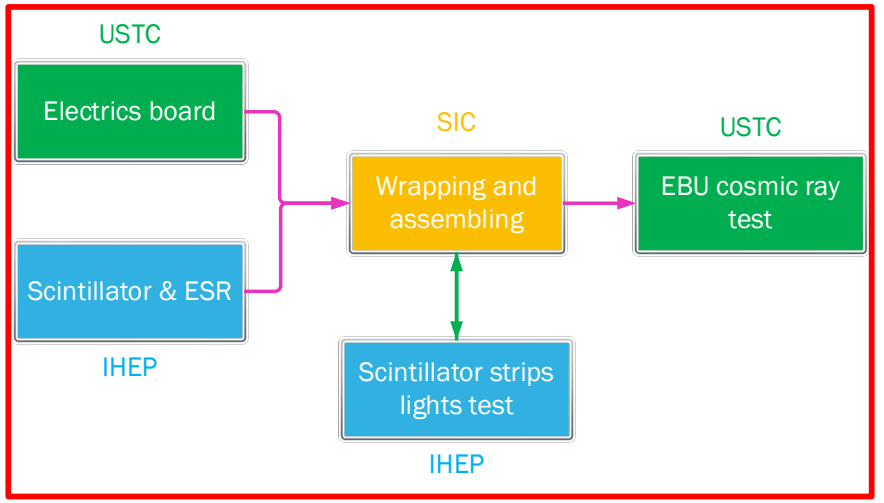

- High energy photon produce process
  - $Higgs \rightarrow \gamma\gamma$ $\sim 100GeV$
  - $BhaBha\ events$ $\sim 125GeV$
  - $ISR\ photons$ $\sim 150GeV$
- The most photon energy <100GeV in CEPC

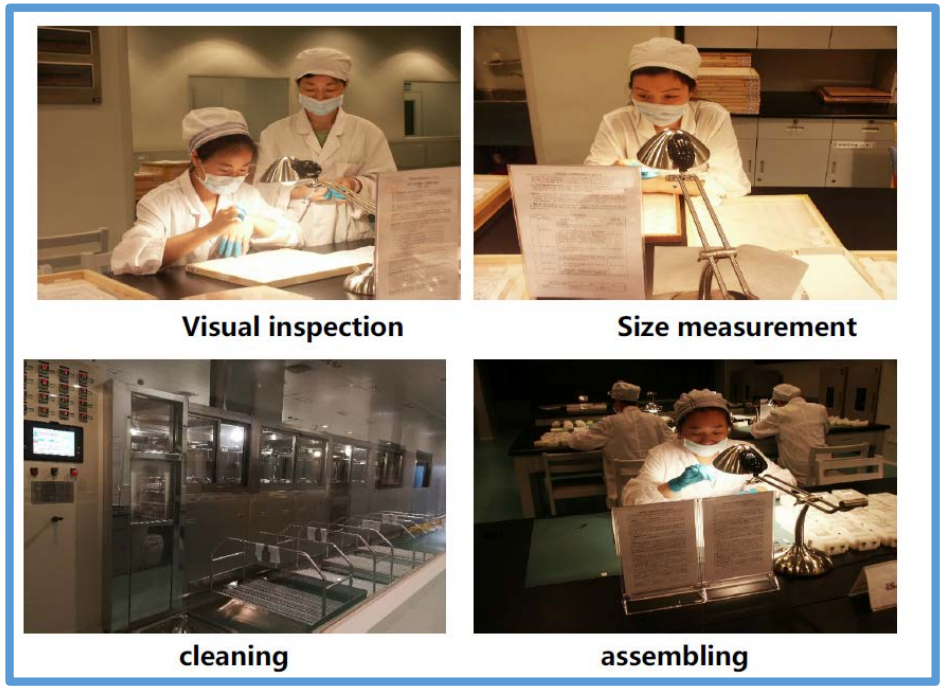
| Energy | 95mm W | 90mm W | 85mm W | 80mm W |
|---|---|---|---|---|
| 175GeV | 99.0% | 98.6% | 97.9% | 96.9% |
| 125GeV | 99.2% | 98.8% | 98.2% | 97.3% |
| 75GeV | 99.4% | 99.1% | 98.7% | 98.1% |

# Wrapped and assembly in SIC (Shanghai Institute of Ceramic)



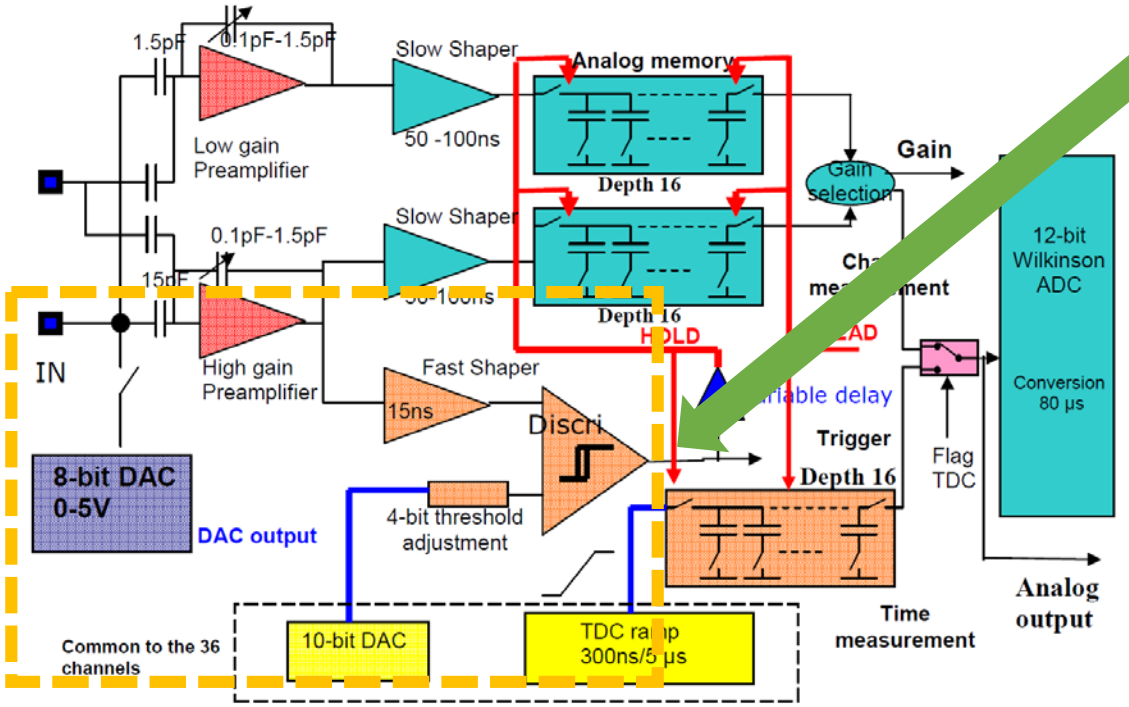





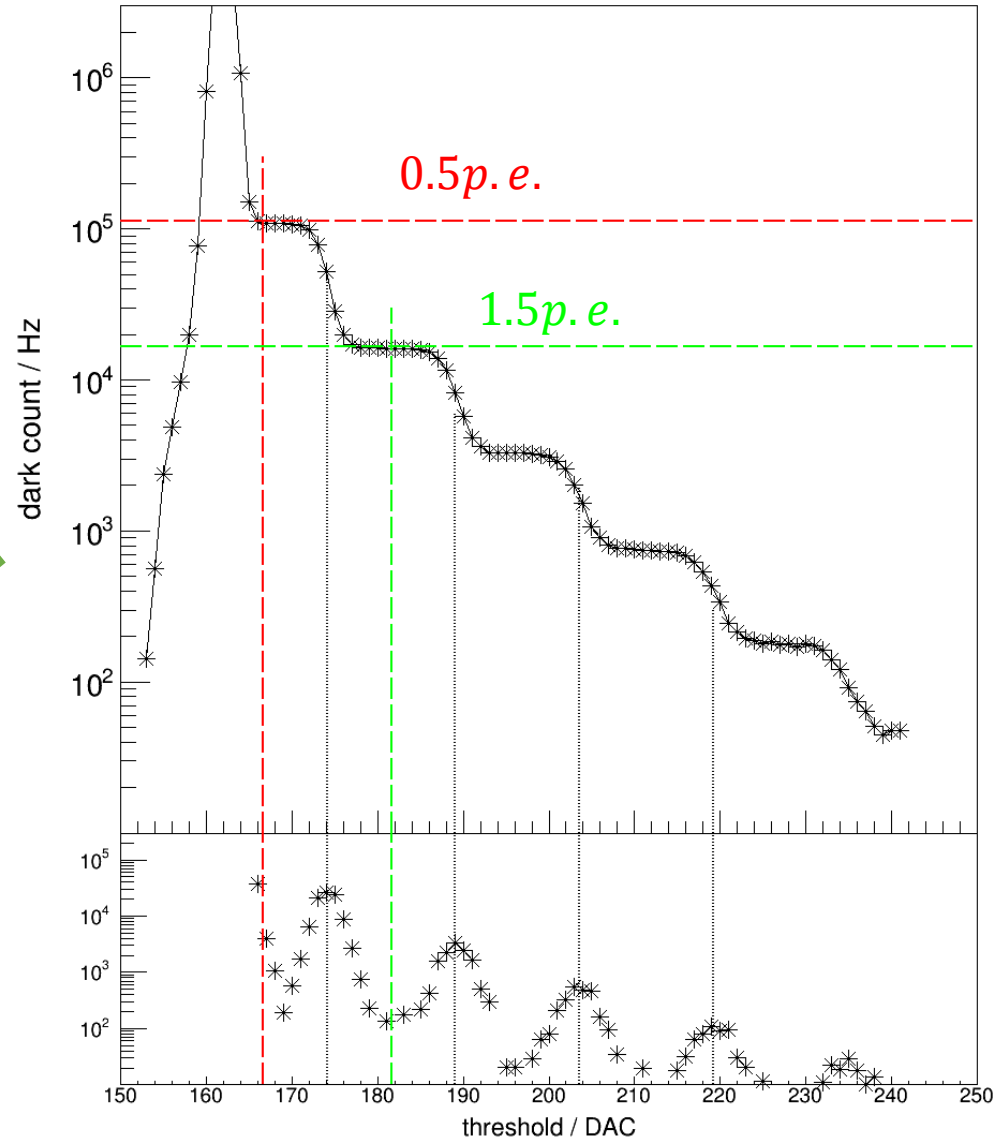



# SP2e – 015P

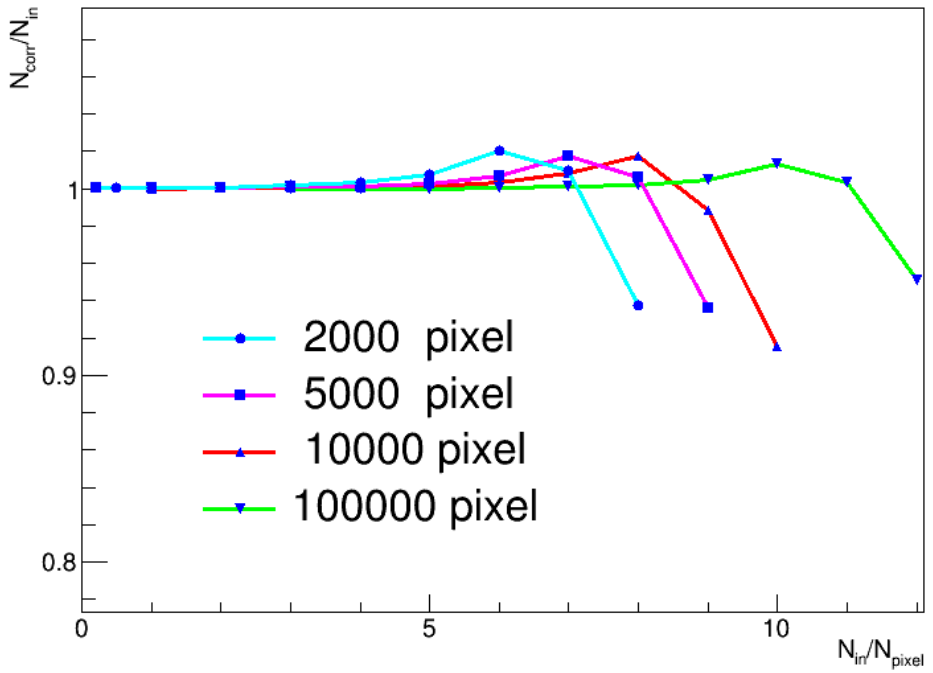
- Shut down ADC portion
- Using DAC scan threshold and counter
  150ns dead time

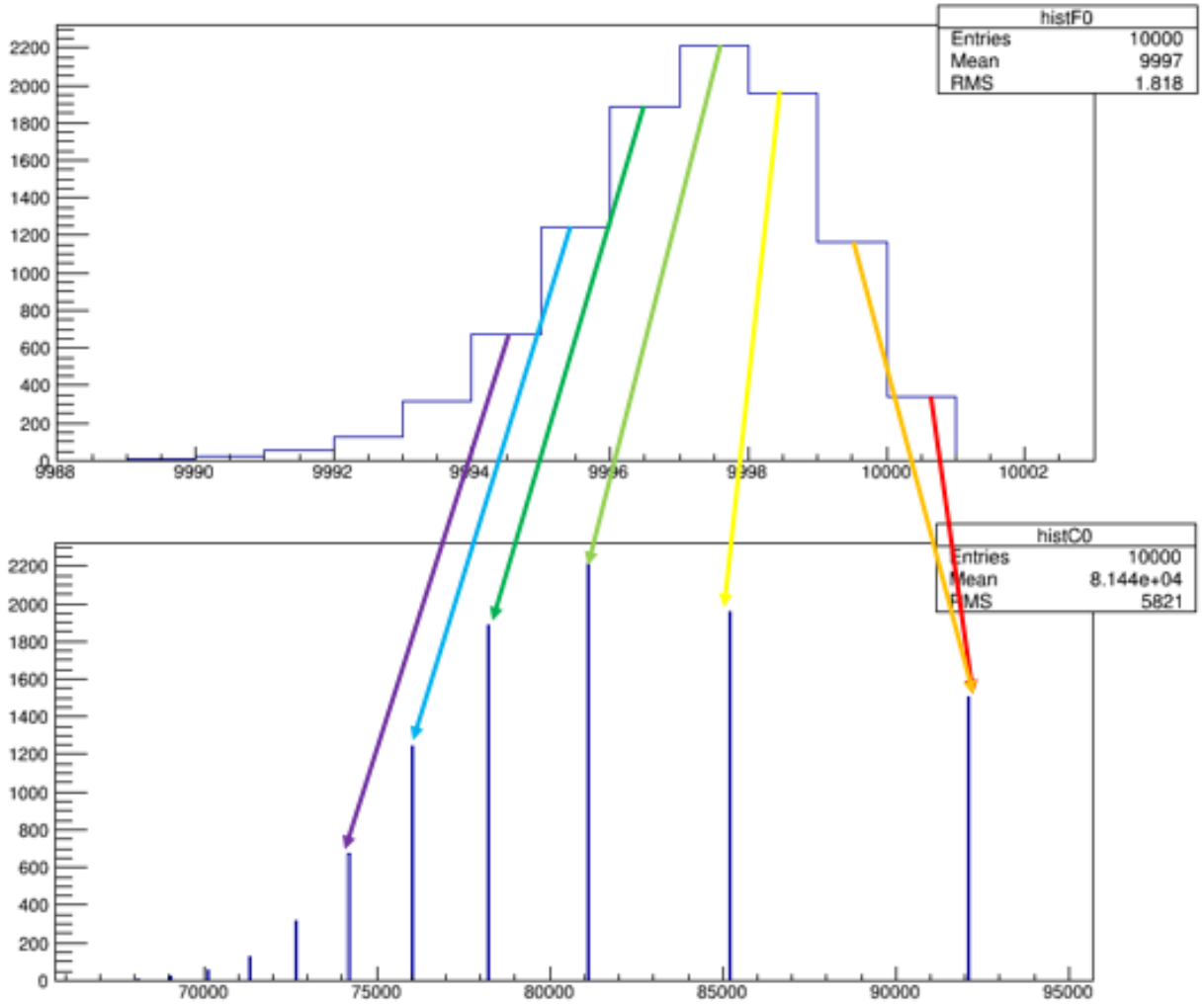



$over\ voltage = 4\ V$

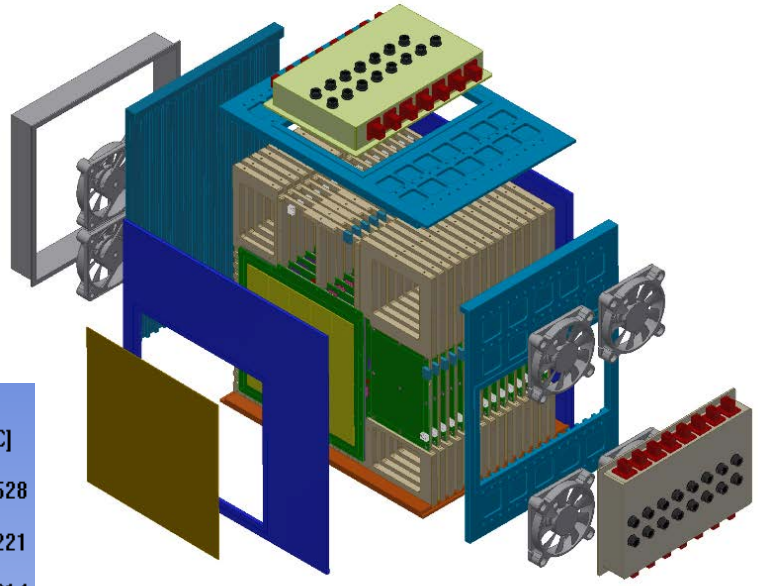


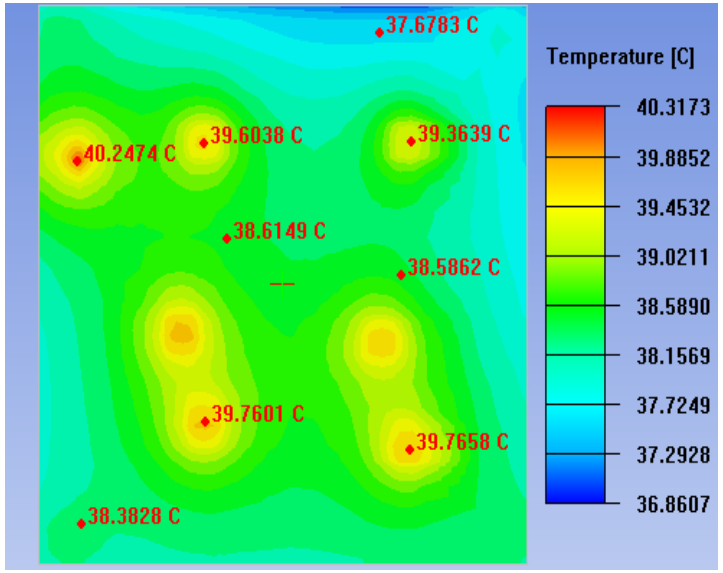
# SiPM Oversaturation



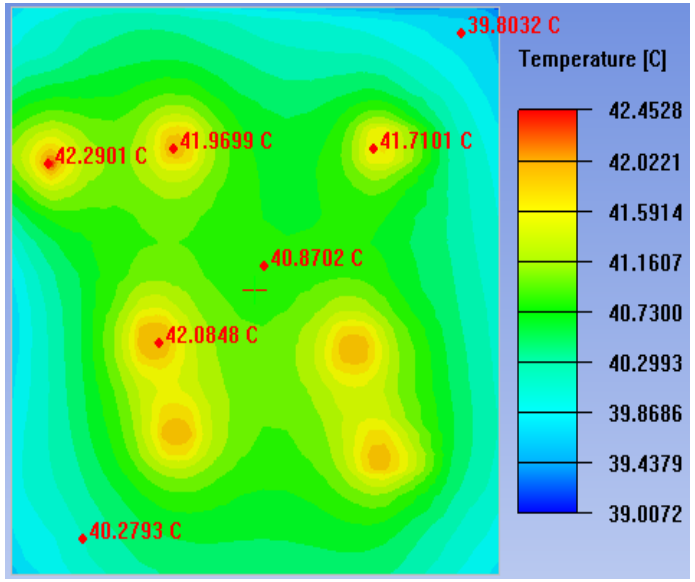
# Cooling system






Layer 5

| | | | | |
|---|---|---|---|---|
| Object min: | 36.8607 | Std dev: | 0.45 | C |
| Object max: | 40.3173 | Area: | 0.0617 | m2 |

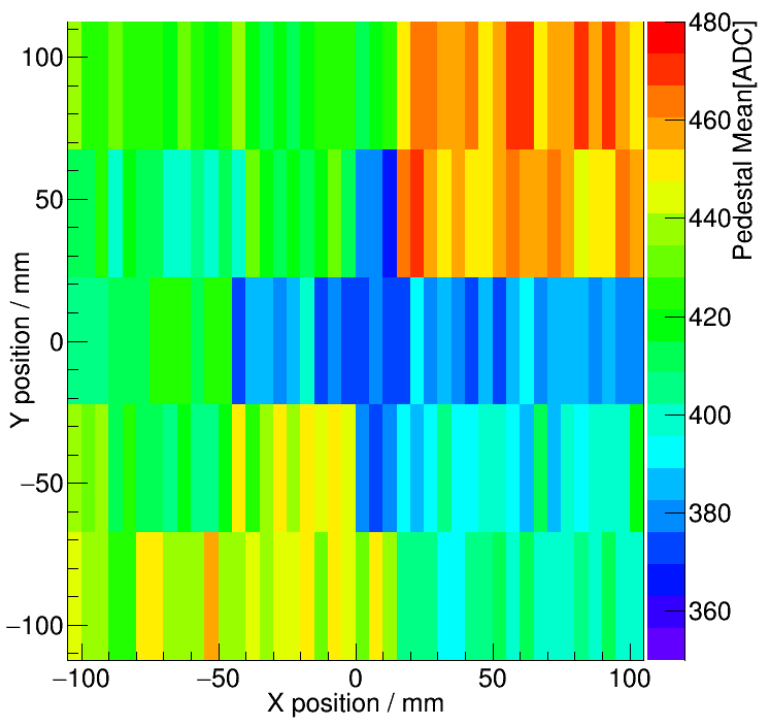


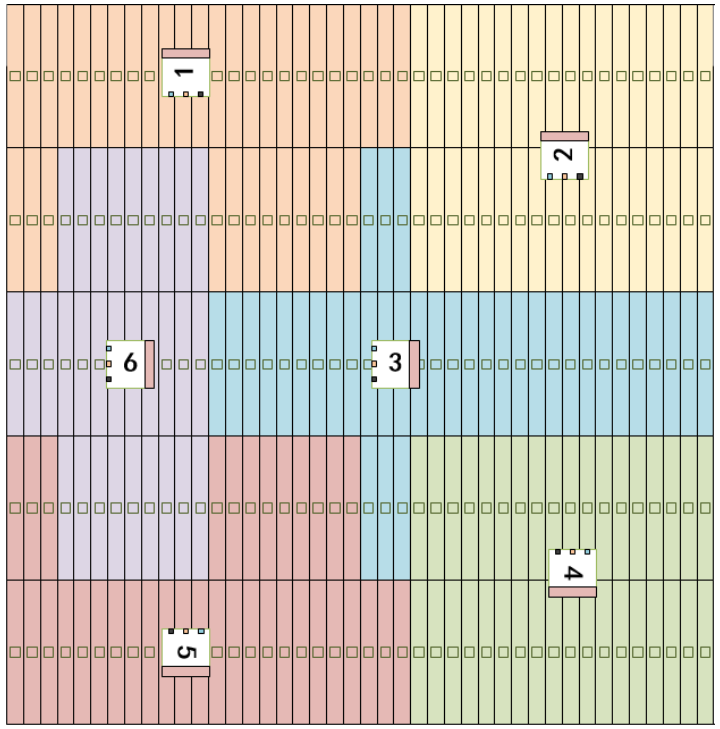

Layer 15

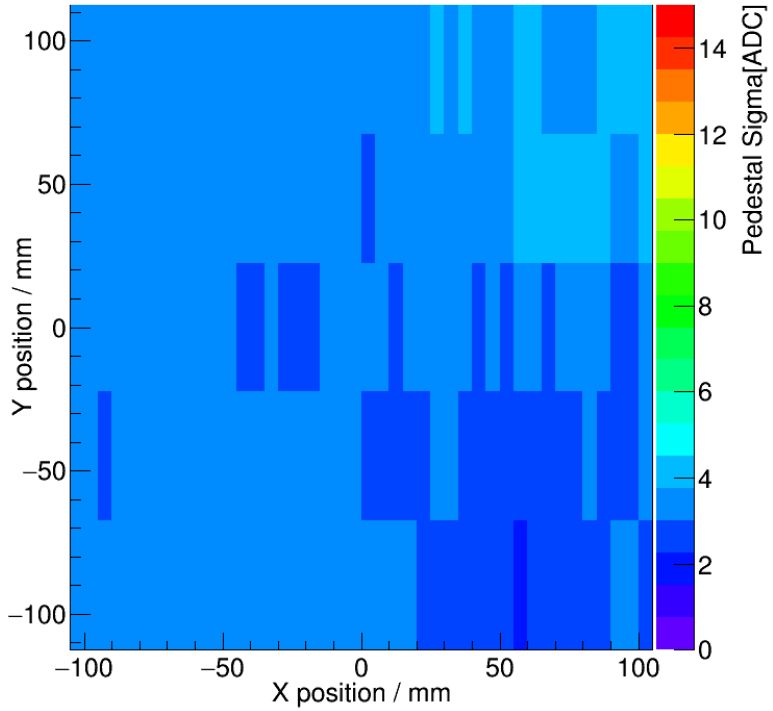
| | | | | |
|---|---|---|---|---|
| Object min: | 39.0072 | Std dev: | 0.495 | C |
| Object max: | 42.4528 | Area: | 0.0617 | m2 |

# Electronics pedestal

SiPM w/o HV

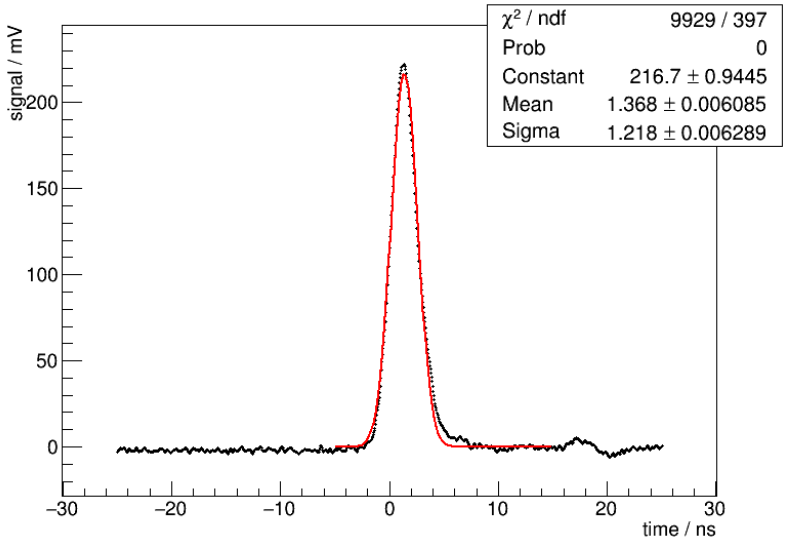


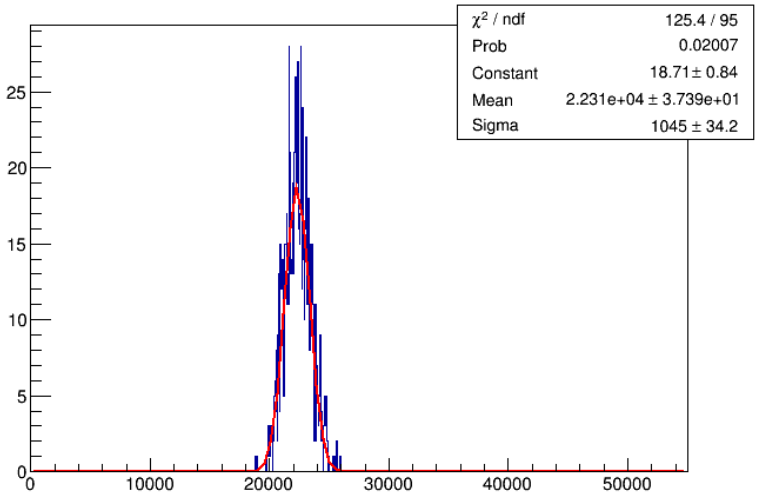



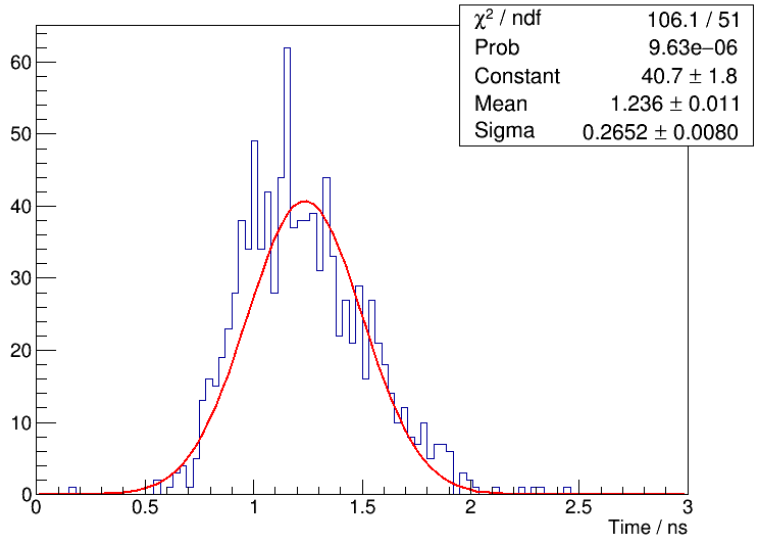



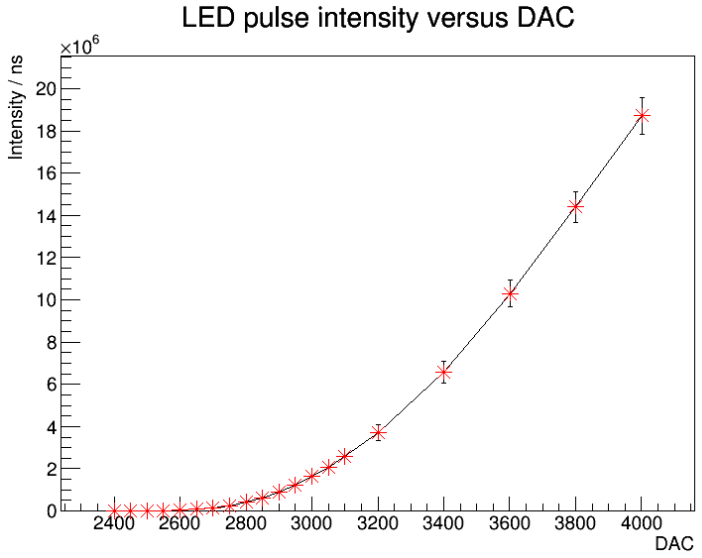

- Pedestal mean various observable for different chips
- Pedestal sigma independent on the chips

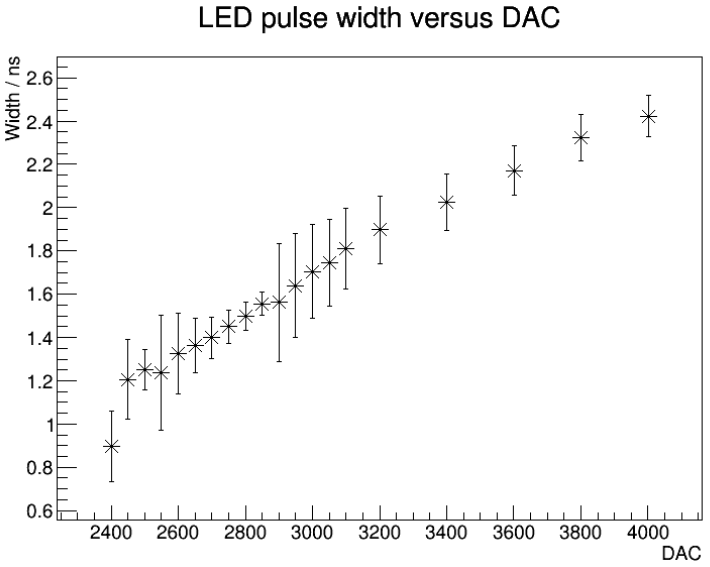
# LED pulse


$\chi^2$ / ndf 9929 / 397
Prob 0
Constant 216.7 ± 0.9445
Mean 1.368 ± 0.006085
Sigma 1.218 ± 0.006289
signal / mV
time / ns


$\chi^2$ / ndf 125.4 / 95
Prob 0.02007
Constant 18.71 ± 0.84
Mean 2.231e+04 ± 3.739e+01
Sigma 1045 ± 34.2

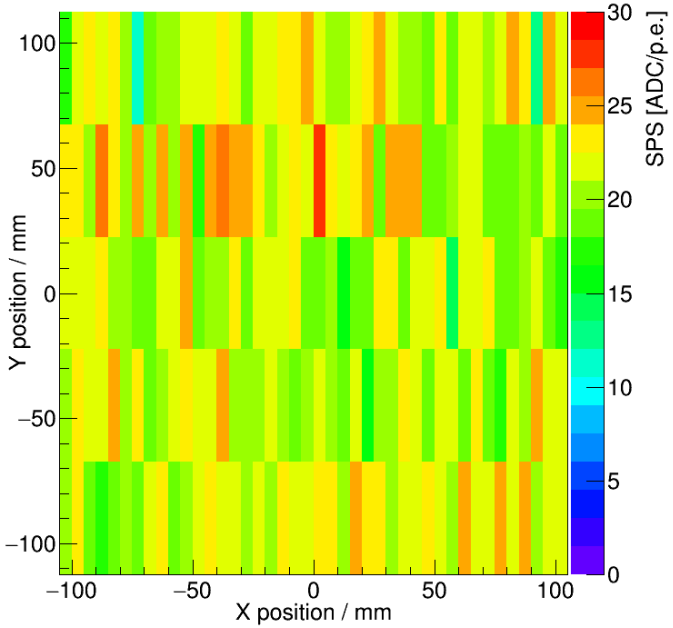

$\chi^2$ / ndf 106.1 / 51
Prob 9.63e−06
Constant 40.7 ± 1.8
Mean 1.236 ± 0.011
Sigma 0.2652 ± 0.0080
Time / ns

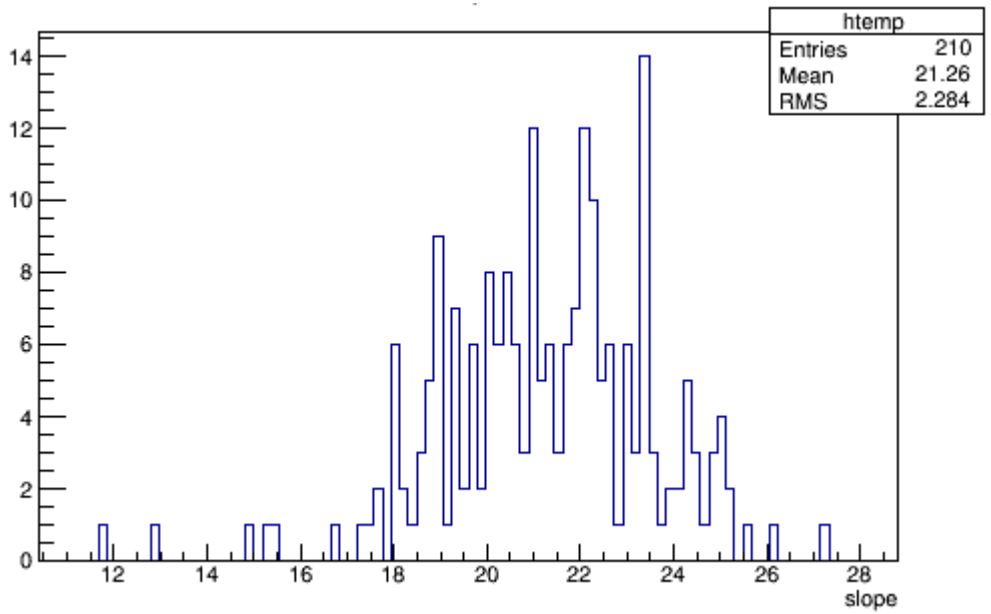

LED pulse intensity versus DAC
×10^6
Intensity / ns
DAC

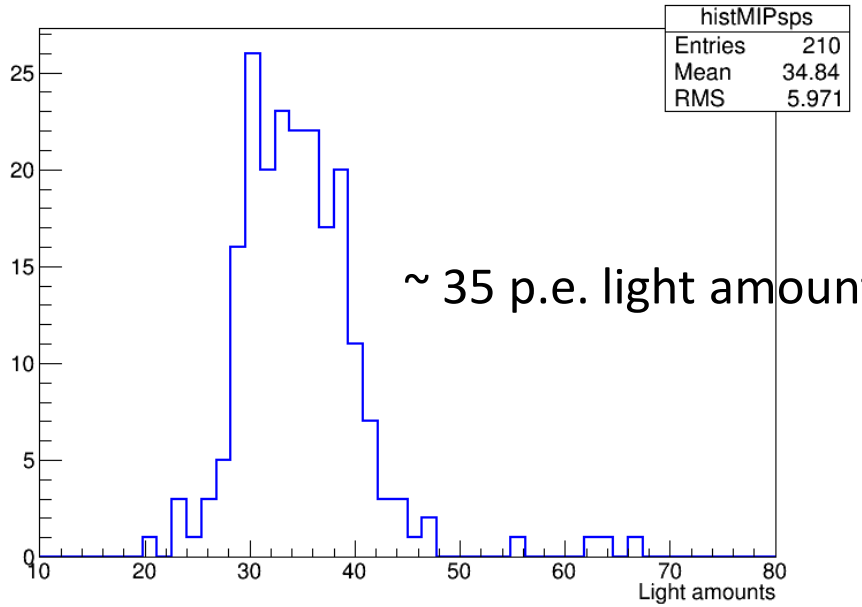

LED pulse width versus DAC
Width / ns
DAC

# LED SPS calibration for 15um EBU

- ✓ DAC scan : 2300-3000
- ✓ Step : 20
- ✓ 10% variant for full channels

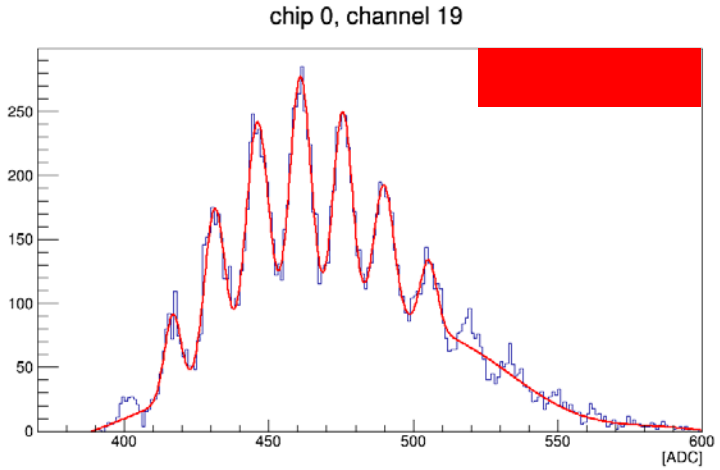


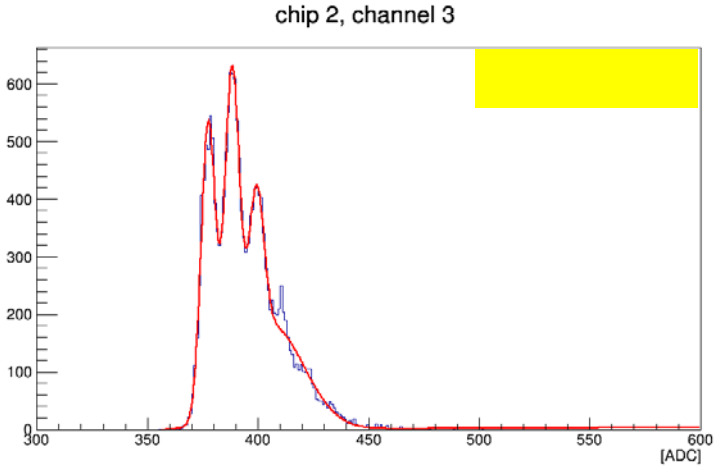



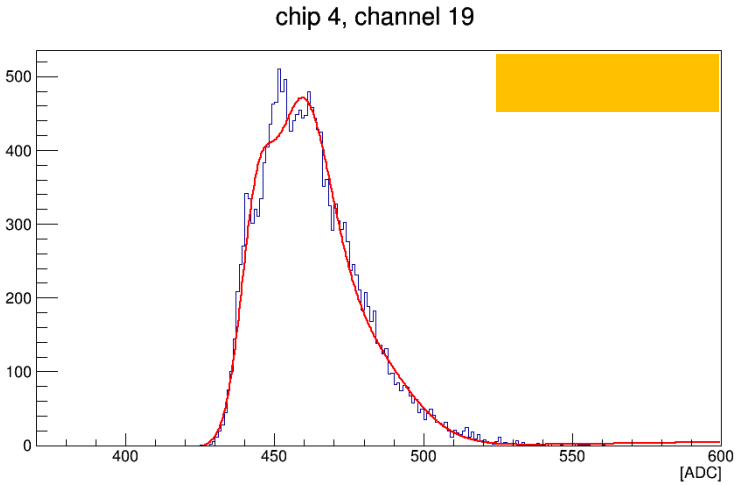



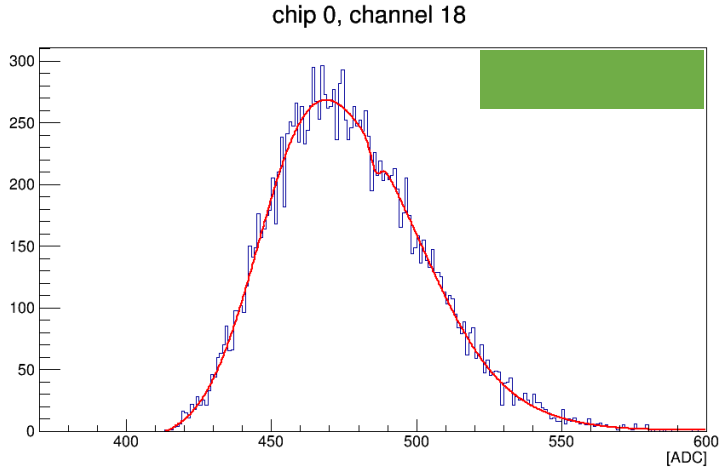

~ 35 p.e. light amounts

# LED SPS calibration for 10um EBU



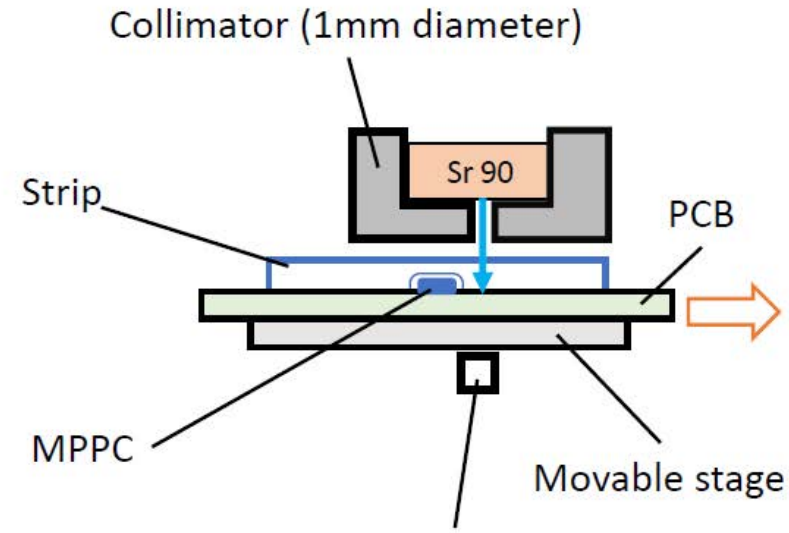




| | |
|---|---|
| 15 | 2400 |
| 19 | 2700 |
| 23 | 2800 |
| 18 | 2600 |
| 22 | 2900 |
| 26 | 2750 |
| 75 | 2850 |
| 77 | 2850 |
| 79 | 2850 |
| 162 | 2500 |
| 158 | 2670 |
| 154 | 2850 |
| 163 | 2400 |
| 159 | 2430 |
| 155 | 2420 |

great
general
bad
failed

# Double-side prototype test setup




Plastic scintillator：EJ-212

Reflector：ESR2 (laser-cut)

MPPC：S12571-015P
(1 mm² 15μm-pixel)