LED-based calibration for ScW-ECAL prototype

Naoki Tsuji[a], W. Ootani[b], R. Masuda[a], T Murata[a], T. Mori[b], L. Liu[a], T. Takeshita[c], Y. Tamaya[c], R. Shirai[c],
Y. Niu[de], Y. Zhang[de], J. Liu[de], M. Dong[df], Z. Wang[df], Y. Liu[df]

[a]The University of Tokyo [b]ICEPP, the University of Tokyo
[c]Shinshu University [d]State Key Laboratory of Particle Detection and Electronics
[e]University of Science and Technology of China [f]Institute of High Energy Physics

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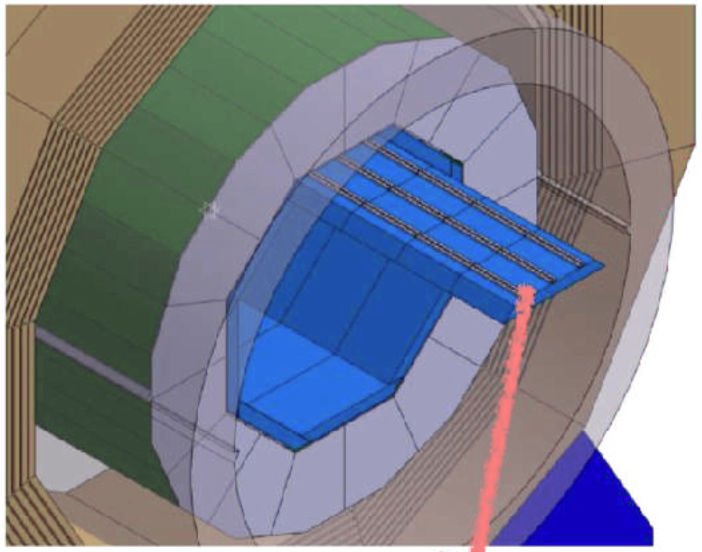
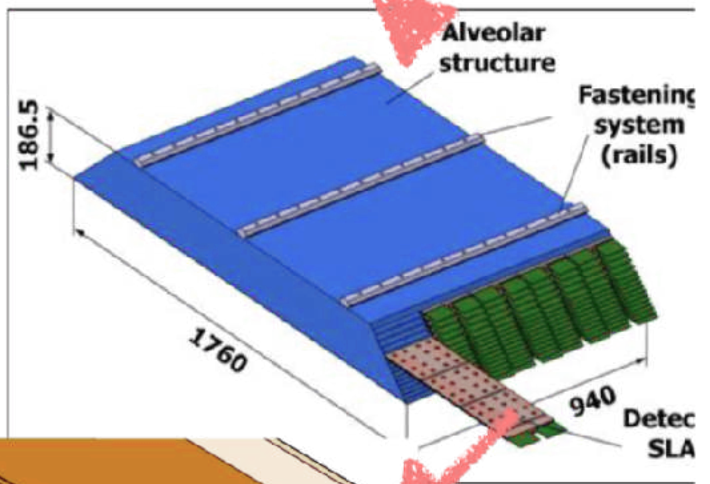
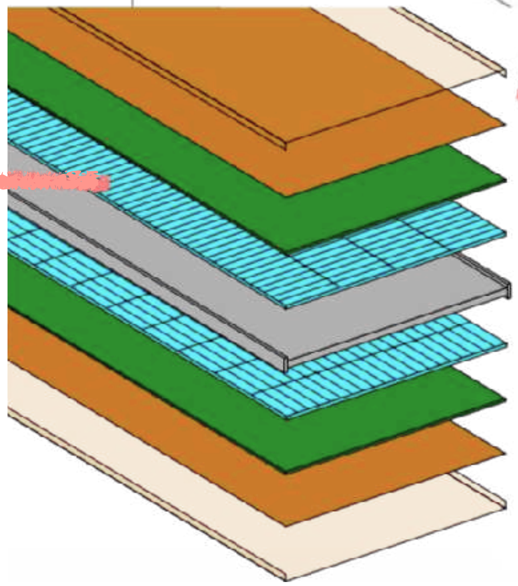
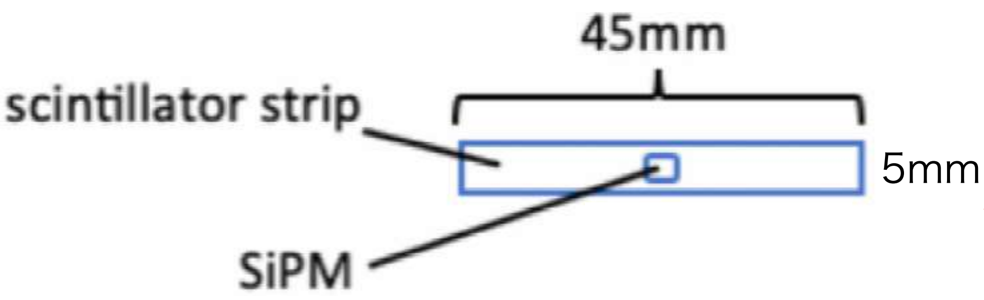
Sc-ECAL

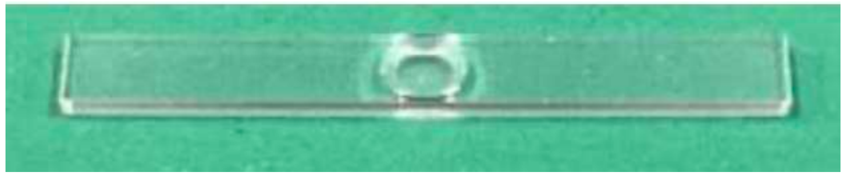
- Scintillator Electromagnetic CALorimeter (Sc-ECAL)
  - Technology option of EM calorimeter for ILC and CEPC
- Based on scintillator strips readout by SiPM
  - $5 \times 45 \times 2$ mm^3 scintillator strip
- Virtual segmentation : 5×5 mm^2 with strips in x-y configuration
  - # readout channels significantly reduced ($10^8 \rightarrow 10^7$) →Low cost
  - Retaining performance comparable to real 5×5 mm^2 segmentation
- Timing resolution < 1 ns







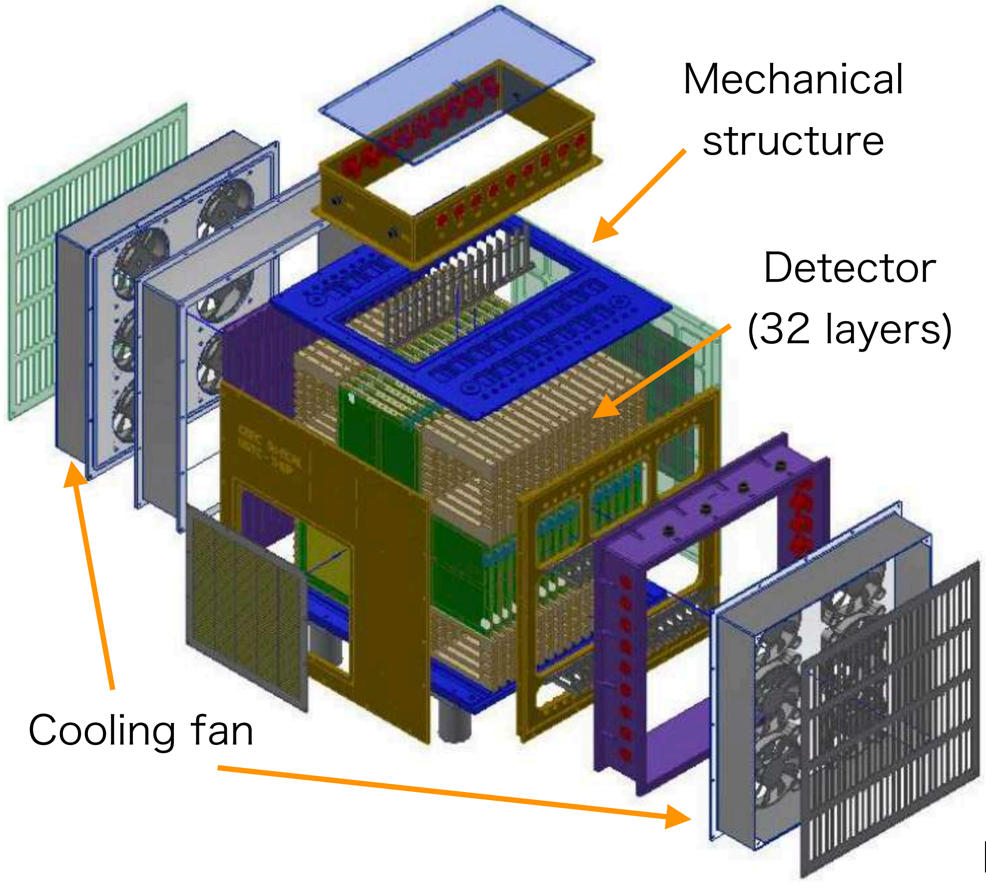




Technological prototype

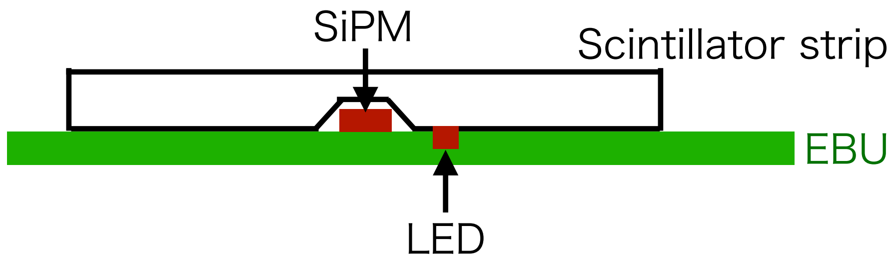
- **Large prototype for Sc-ECAL has been constructed as a joint effort by R&D groups for ILC-ILD and CEPC-ECAL**
  - Use the same technology as foreseen in the full scale detector
  - Evaluate the performance using full layers (32 layers)
- Two detection layers with double SiPM readout developed by UTokyo group have been installed in the prototype
- Two additional layers developed by Shinshu group will also be installed

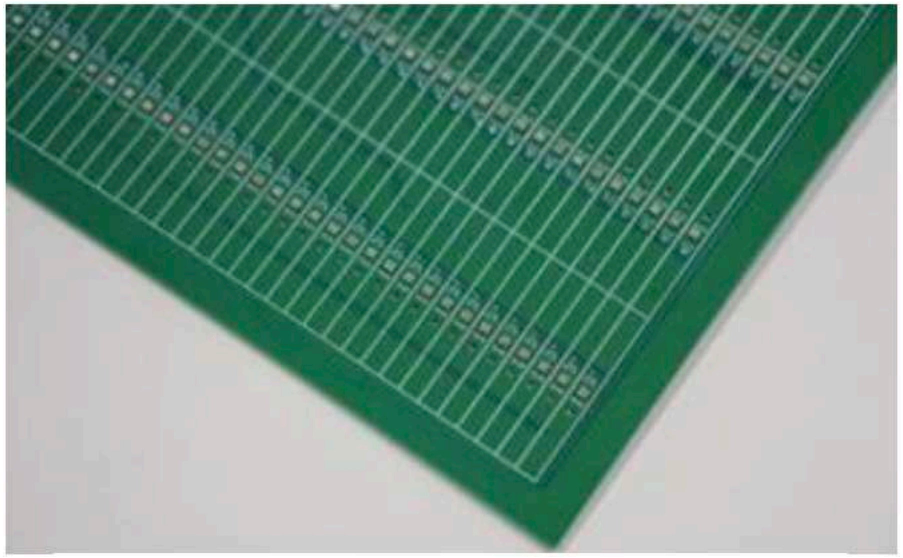
- Test beam in DESY
  - August 2020 and March 2021 has been postponed
    - Due to COVID-19
  - Possibility of test beam at IHEP is under investigation

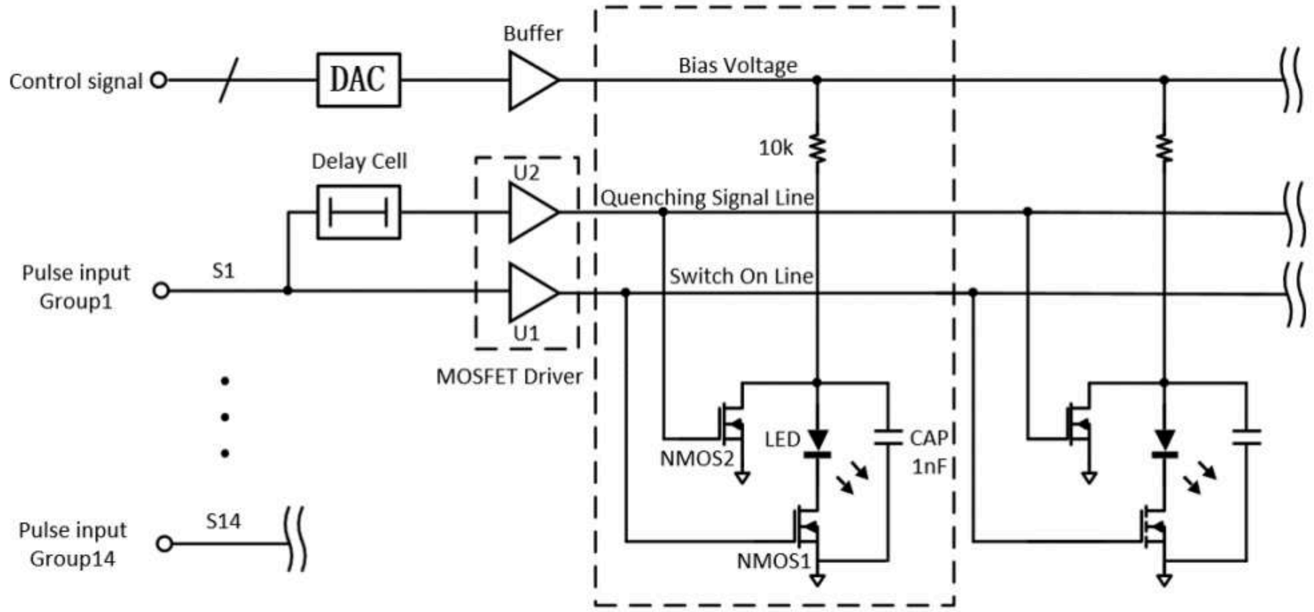


LED calibration

- LED calibration
  - Inter calibration of low gain and high gain for electronics
  - SPS gain calibration of SiPMs
  - Calibration of cross-talk and after-pulse
- System
  - Dual-NIMOS controlled LED system
    - Equipped in EBU
    - One LED for each channel
  - LED: narrow blue light pulse
- Data taken at different LED intensities



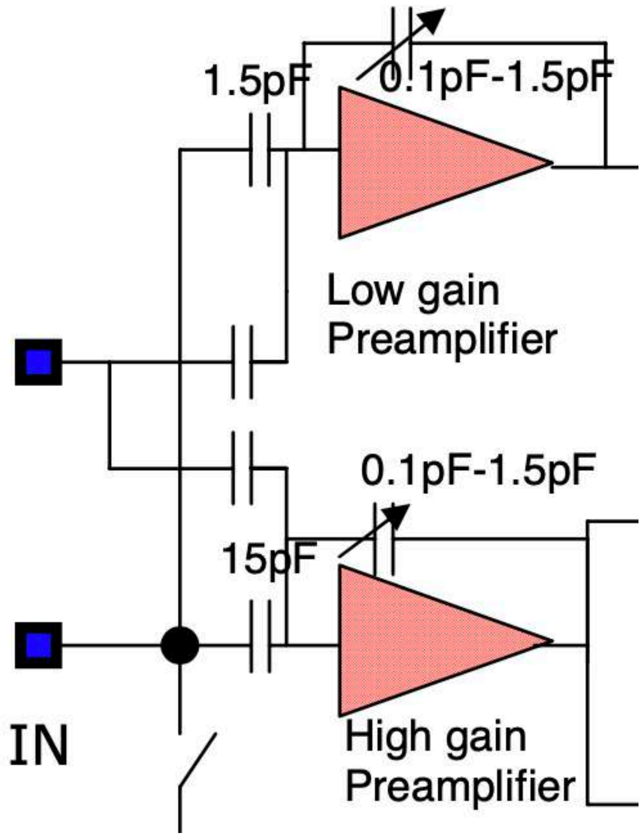


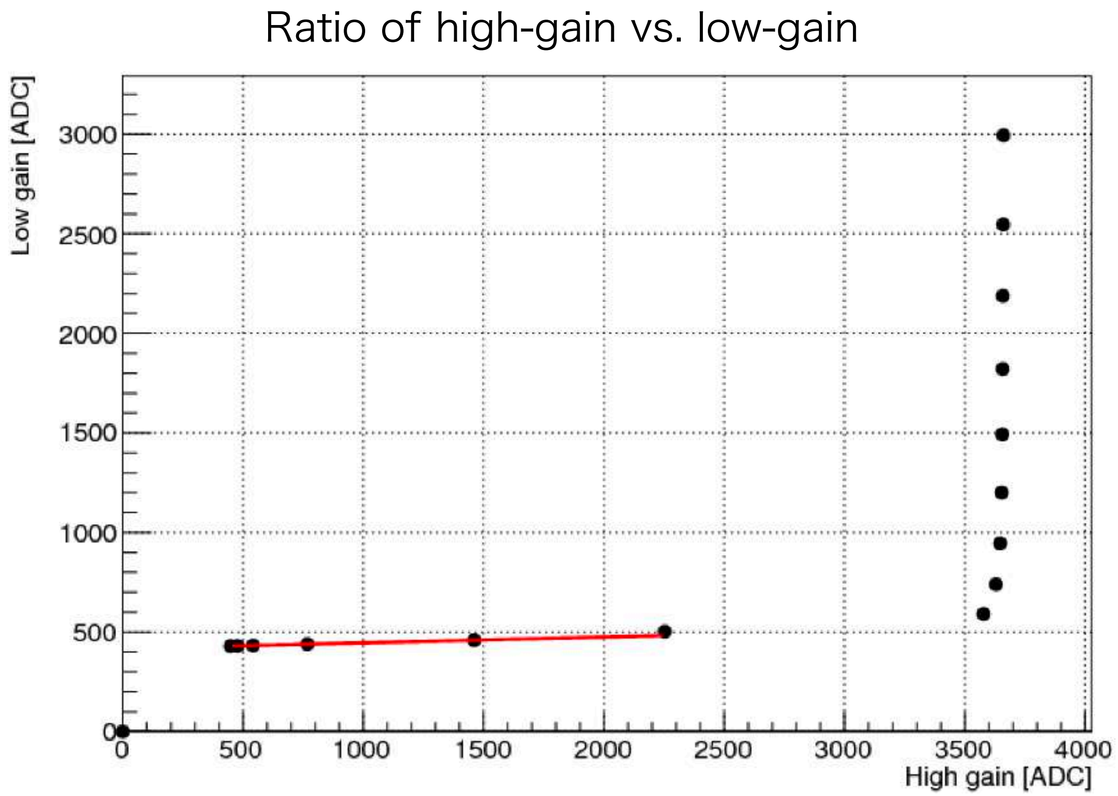


Inter calibration

- SPIROC2E has high-gain and low-gain preamplifier
  - Inter calibration (charge injection) between high-gain and low-gain is needed
  - Data is taken by the mode which records both high-gain and low-gain

- Compare ADC counts of high-gain and low-gain at different LED intensities
  - Inter-calibration factor can be obtained by the ratio
    - Overlapped (linear fitting) region is only at low LED intensities
    - Due to the saturation of high-gain

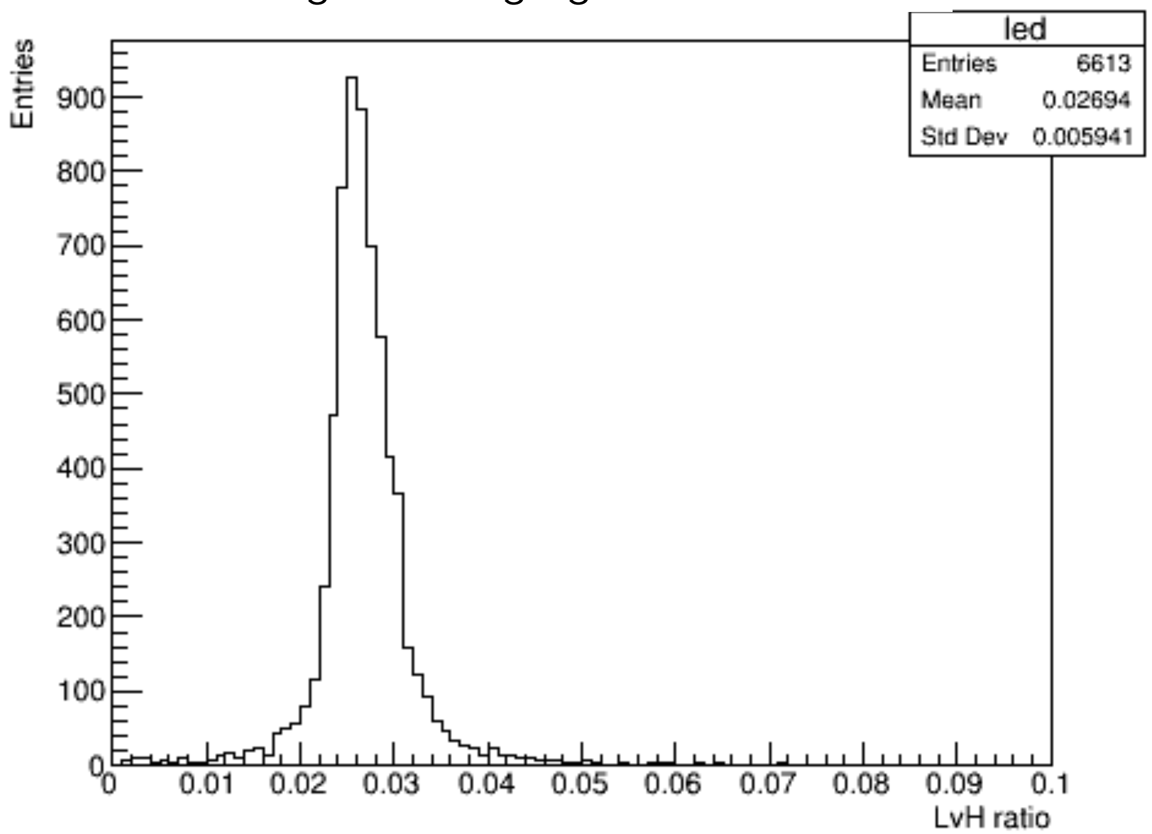




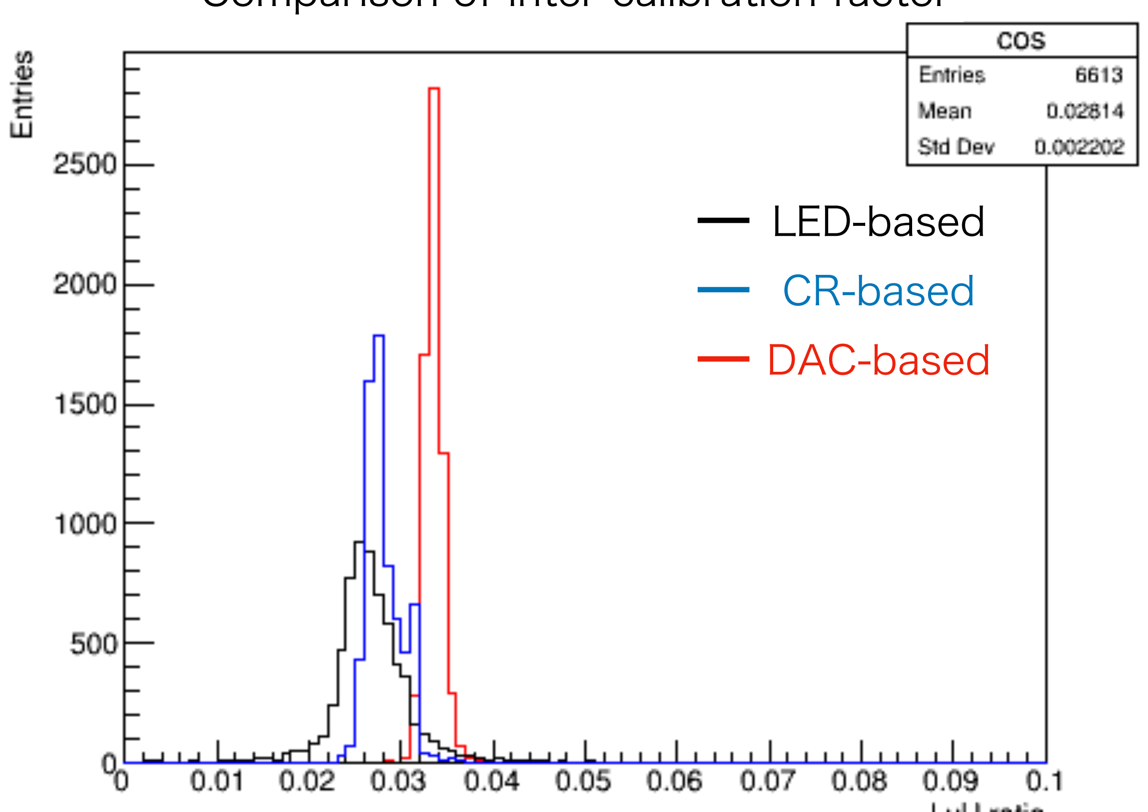
Results & comparison

- Inter-calibration factor can be obtained for all channels
- Inter calibration with different methods
  - LED-based: LED scan
  - DAC-based: directly inject the charge from DAC to SPIROC2E
  - Cosmic-ray (CR-based): cosmic-ray test recording both the high-gain and low-gain
- CR-based inter calibration agree with LED-based one, but DAC-based one is larger than them
  - This difference may come from the difference of signal waveforms
- The spread of the CR-based inter calibration is smaller w.r.t. LED-based one
  - Some channels with LED-based don't have enough fitting points
  - due to the narrow overlapped region and the limit of the interval of LED intensities

Low-gain vs. high-gain ratio with LED



Comparison of inter calibration factor

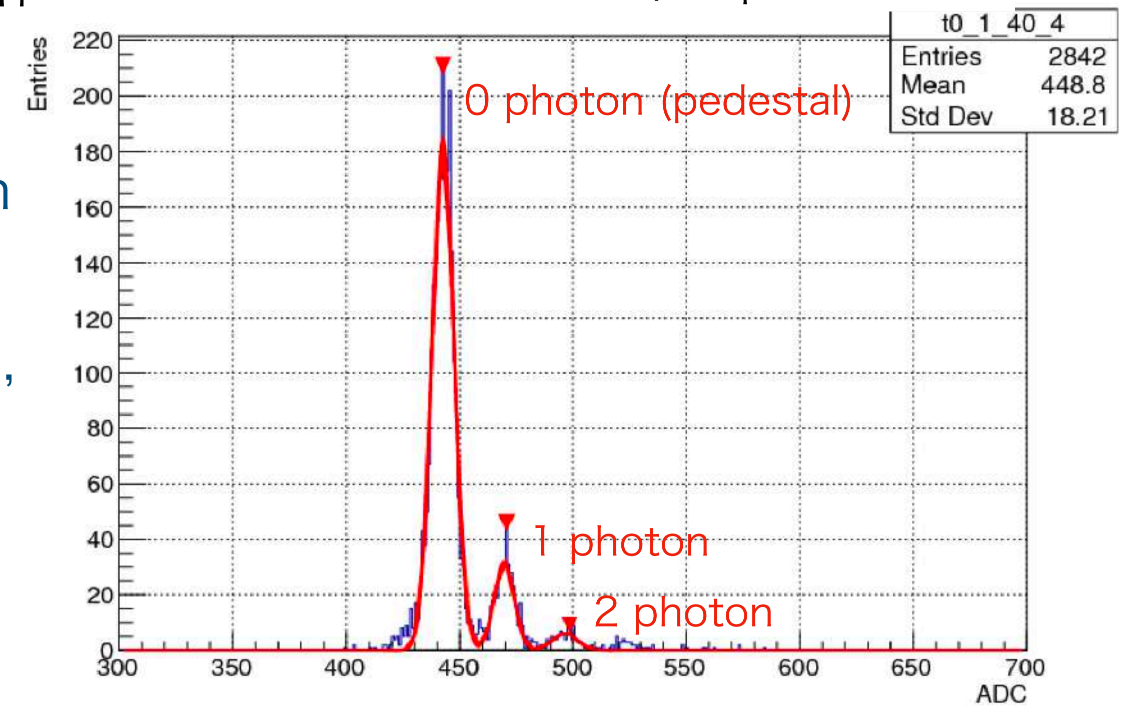


Gain & CTAP calibration

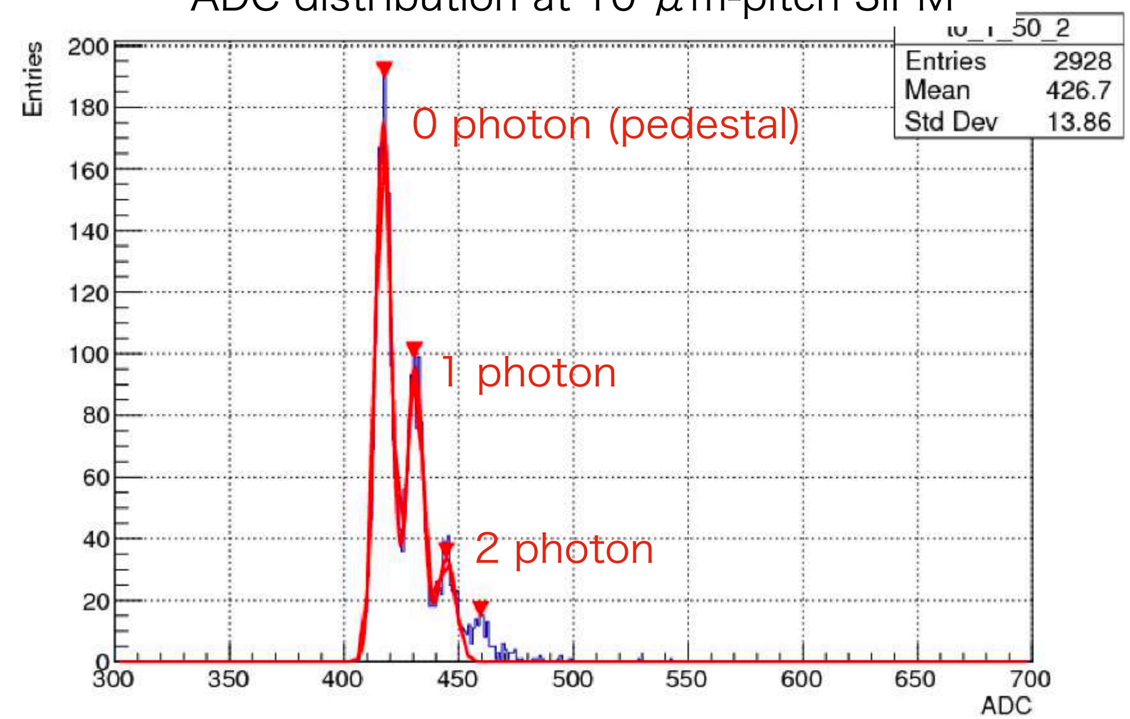
- Gain (one photoelectron charge) can be used to convert the charge to the number of photoelectron
- LED input the light with a few photoelectrons
  - The separated peaks of 0, 1, 2, ··· photons can be obtained
  - Gain is defined by the gap of the peaks of 0, 1, 2, ··· photons

- Using LED data, the probability of cross-talk (CT) and after-pulse (AP) can be calculated
- They may affect the energy reconstruction and saturation correction
  - CT and AP increase absolute signal size
  - Easy to saturate

ADC distribution at 15 μm-pitch SiPM



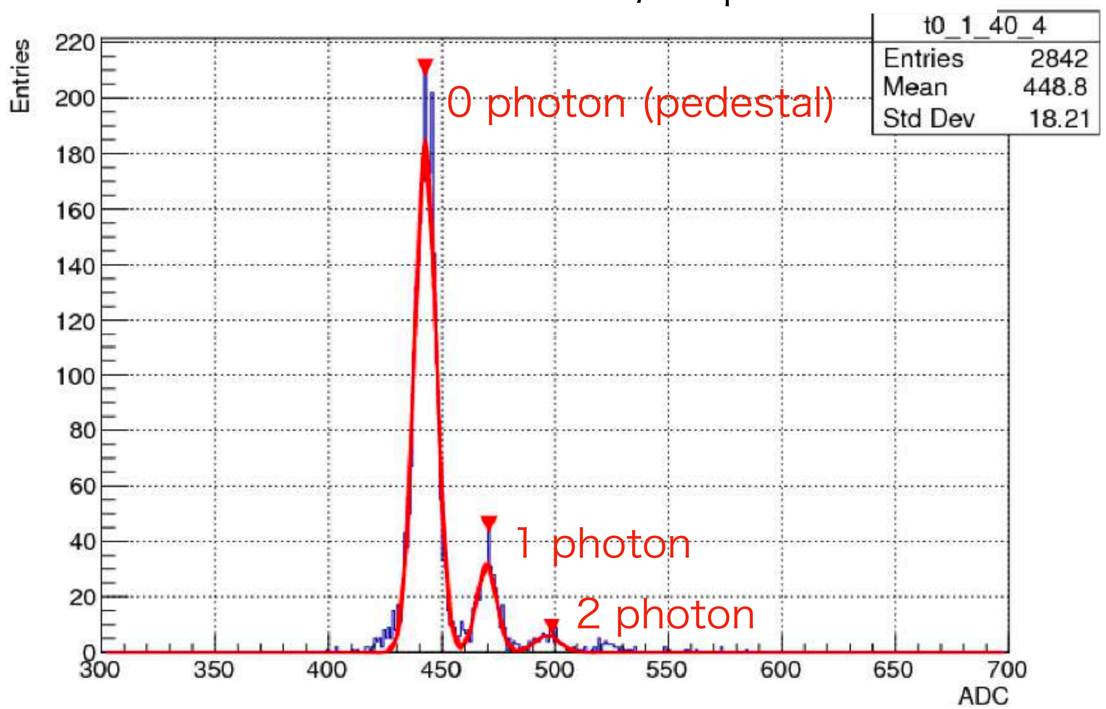
ADC distribution at 10 μm-pitch SiPM



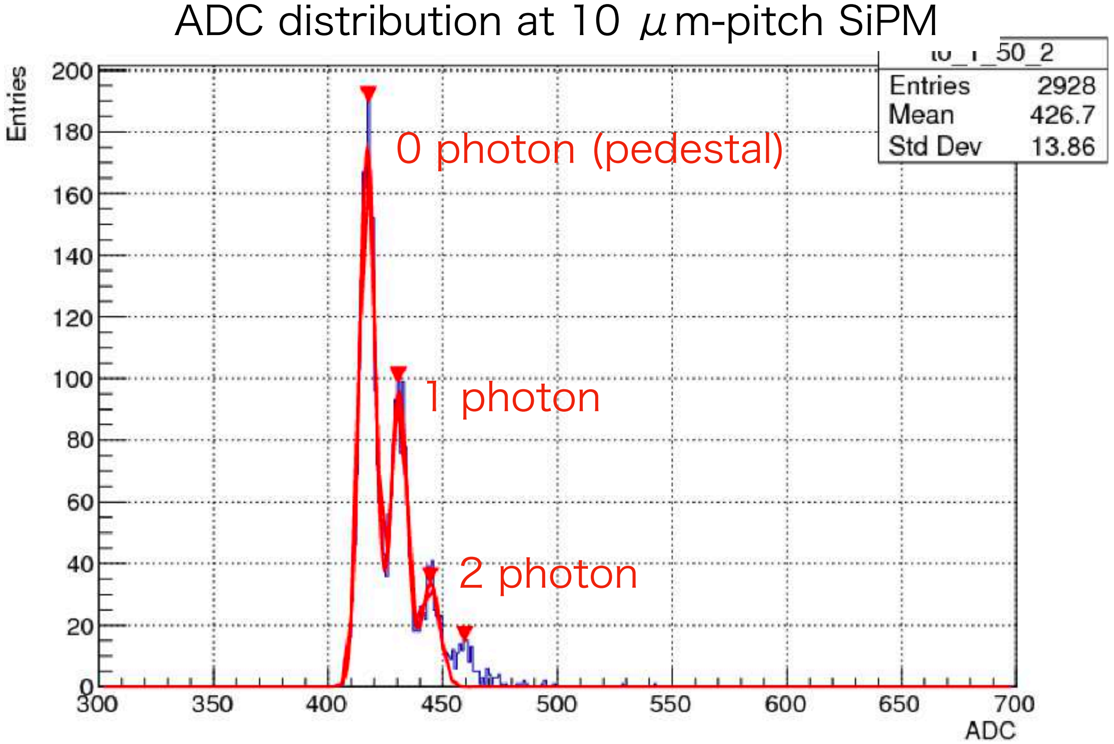
CT+AP measurement

- Assume the signal distribution of LED data at low light intensity is Poisson
- Probability for 0 and 1 photon in case of no CT + AP
  - $P(0) = e^{-\mu}$
  - $P(1) = \mu e^{-\mu}$
- CT and AP do not affect P(0) but decrease P(1)
  - $P'(1) = (1-\chi)\mu e^{-\mu}$
- The CT+AP probability χ is calculated as
  - $\chi = 1 - \frac{P(1)}{P(0) log P(0)}$
- Fit 0, 1, 2 photon peaks with multi-gaussian
- Calculate P(0) and P(1) using the fitted gaussian function
  - Integrated gaussian / total entries

ADC distribution at 15 μm-pitch SiPM



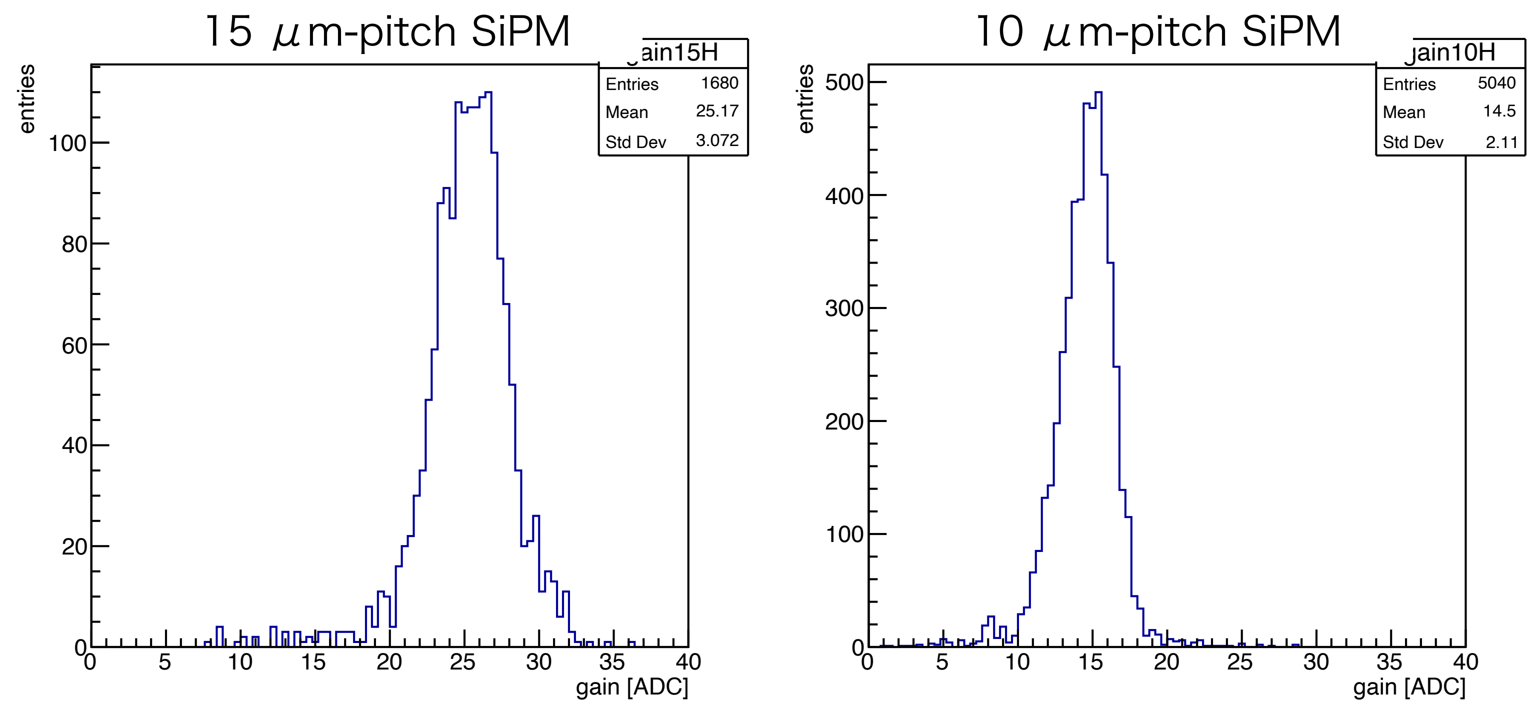
ADC distribution at 10 μm-pitch SiPM



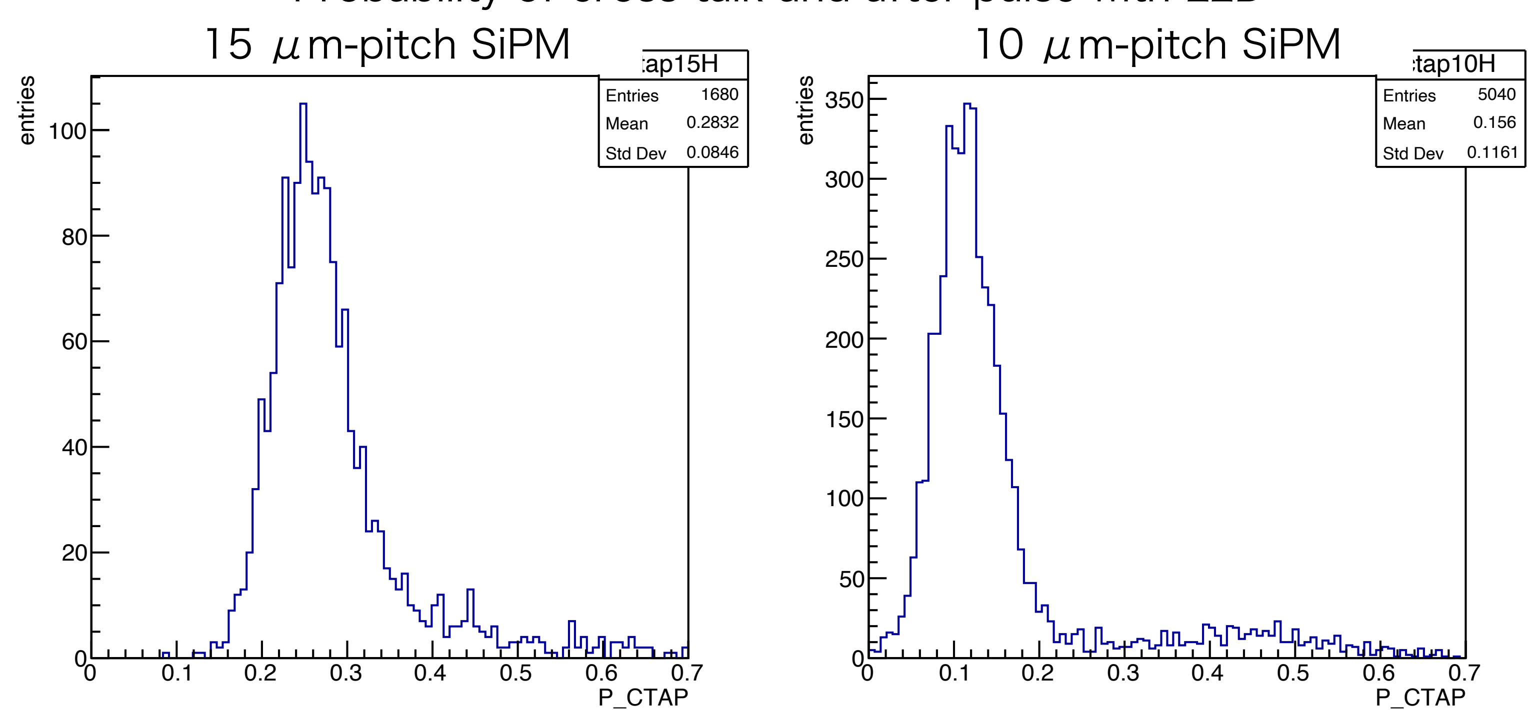
Results

- Gain and CTAP probability for all channels
- Reasonable CTAP probability obtained
  - Catalogue values of CT probability is 5% at 10 μm-pitch, 15% at 15 μm-pitch
  - AP probability is usually 5-10%
- Except some tails where calculation failed due to too low or high light intensity

Gain (single photoelectron charge) with LED

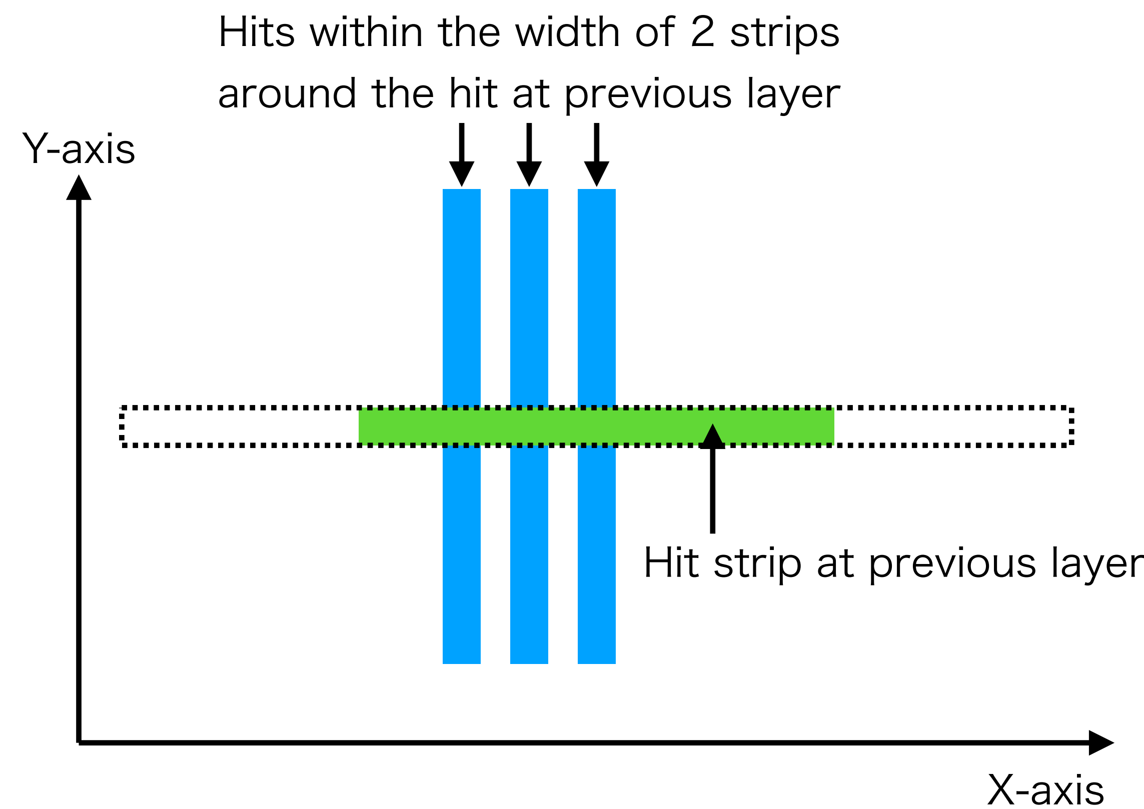


Probability of cross-talk and after-pulse with LED

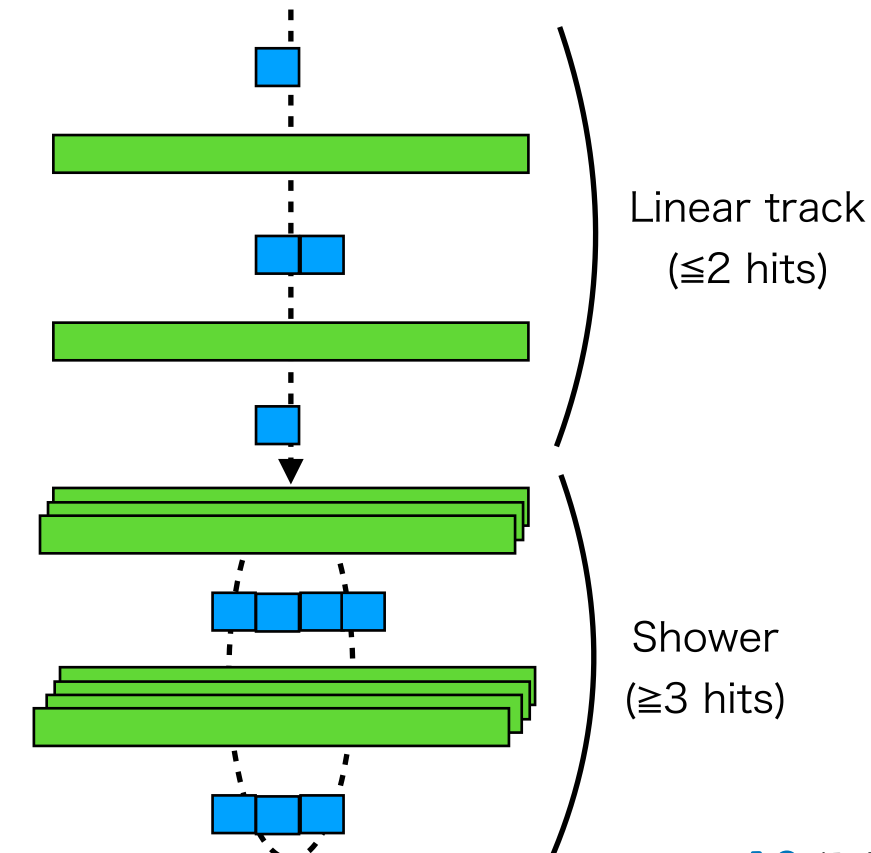


Shower study using cosmic-ray

- Shower search in cosmic-ray events
  - Possibility of performance study using cosmic-ray shower events is being considered
  - Comparison with simulation



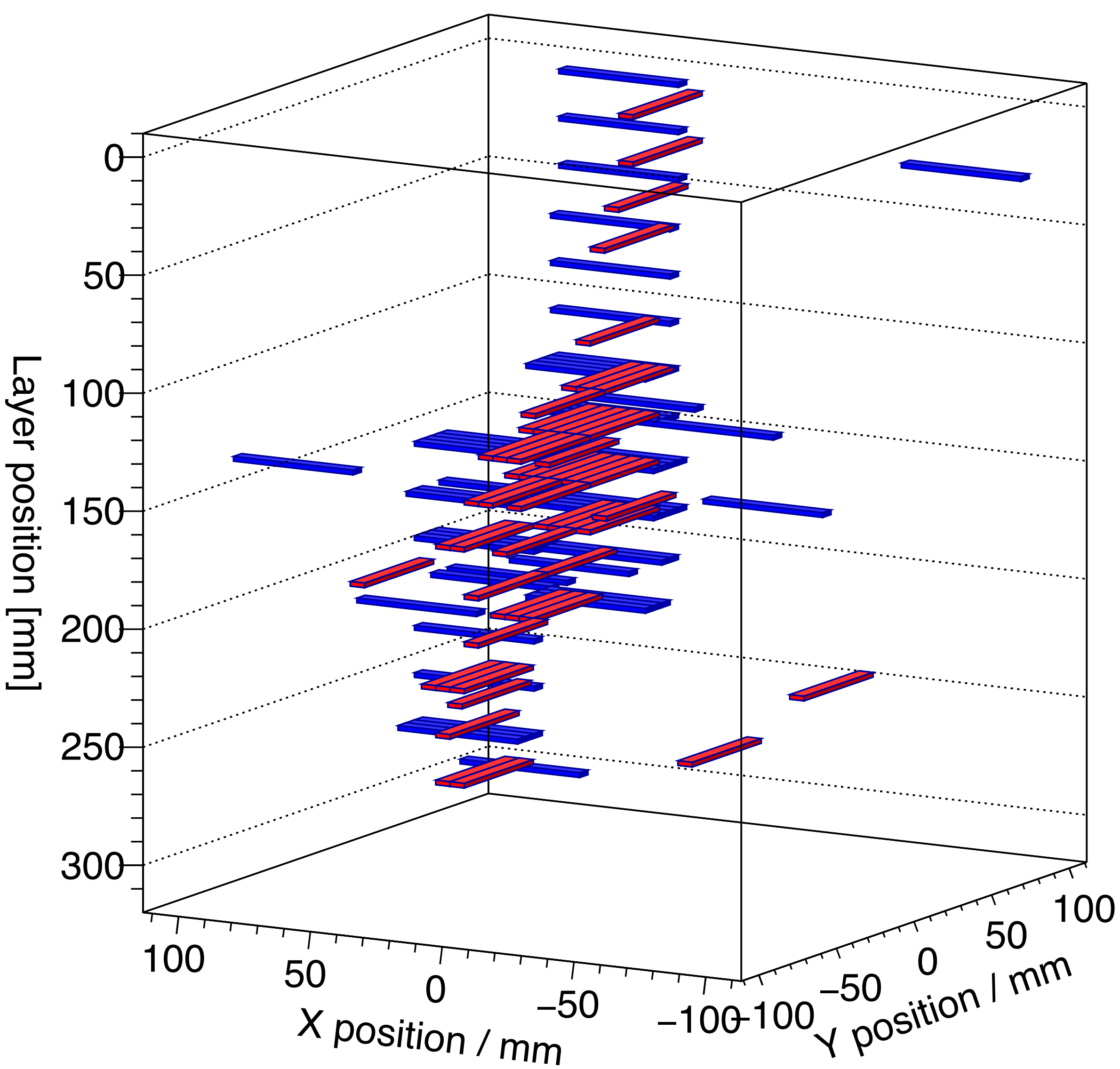
- Shower finding algorithm
  - Get the hit position at previous layer
  - Search the hits at focused layer
    - Count the hits within the width of 2 strips around the hit at previous layer
    - ≦2 hits is just a particle track
    - ≧3 hits may cause the shower
  - Search the events which consist of linear track and shower
    - Search the ≧3 hits at the continuous 3 layers after the linear region



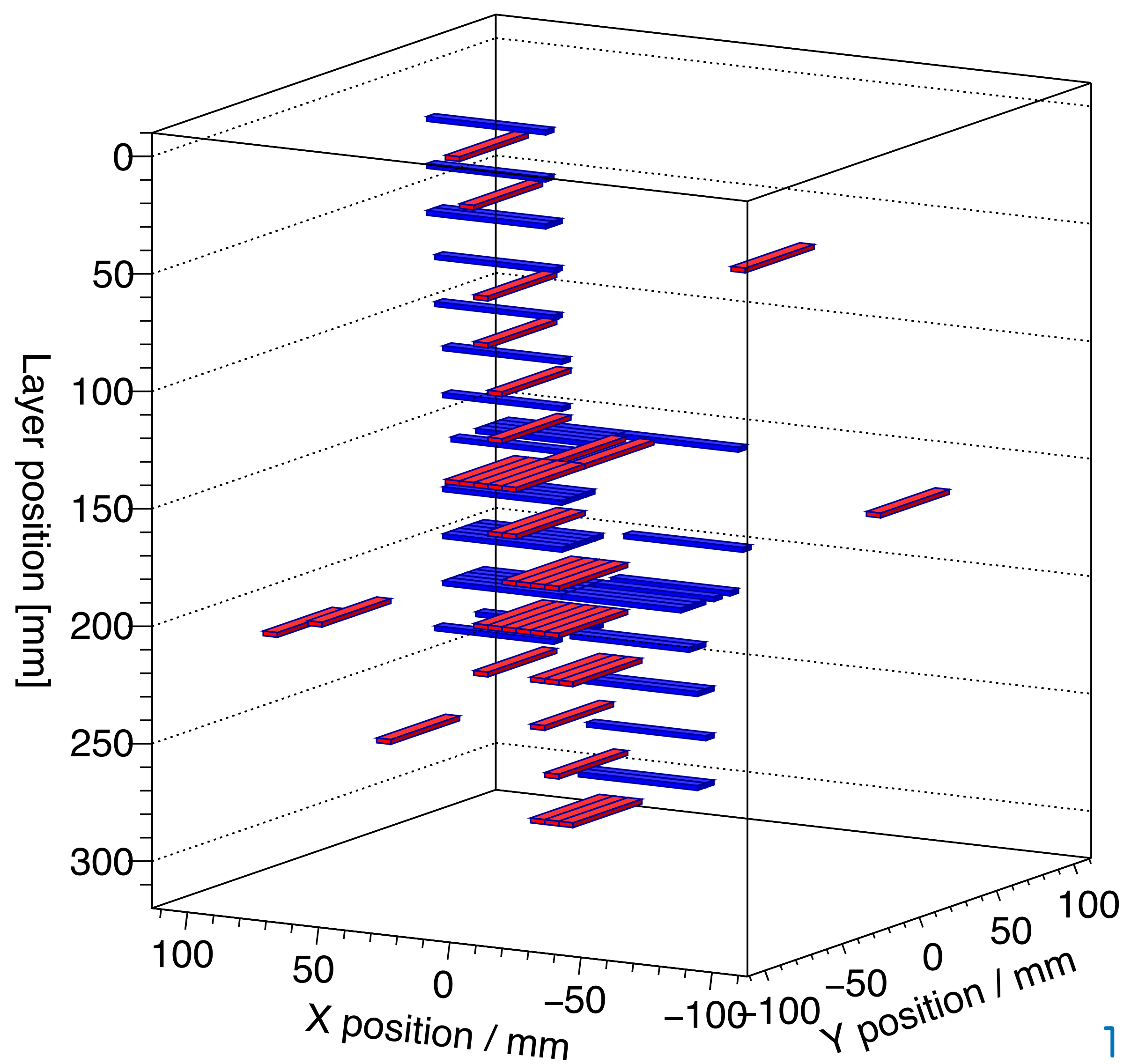
Results

- Some shower-like events can be obtained
  - 630 shower events in 1.75 * 10^6 cosmic-ray events
- Fully contained shower events are not included due to coincidence trigger with top and bottom layers

EventID : 0



EventID : 2



Simulation

- Comparison of CR shower events between data and simulation
- Simulation setup
  - Standalone package based on Geant4
    - Version: Geant4-10.04-p02
    - Physics list: QGSP_BERT
  - Sc-ECAL prototype
    - 30 layers
    - Absorber: WCu (85:15) 3.2 mm
  - Cosmic-ray shower library (CRY) used
    - The CRY software library generates correlated cosmic-ray particle

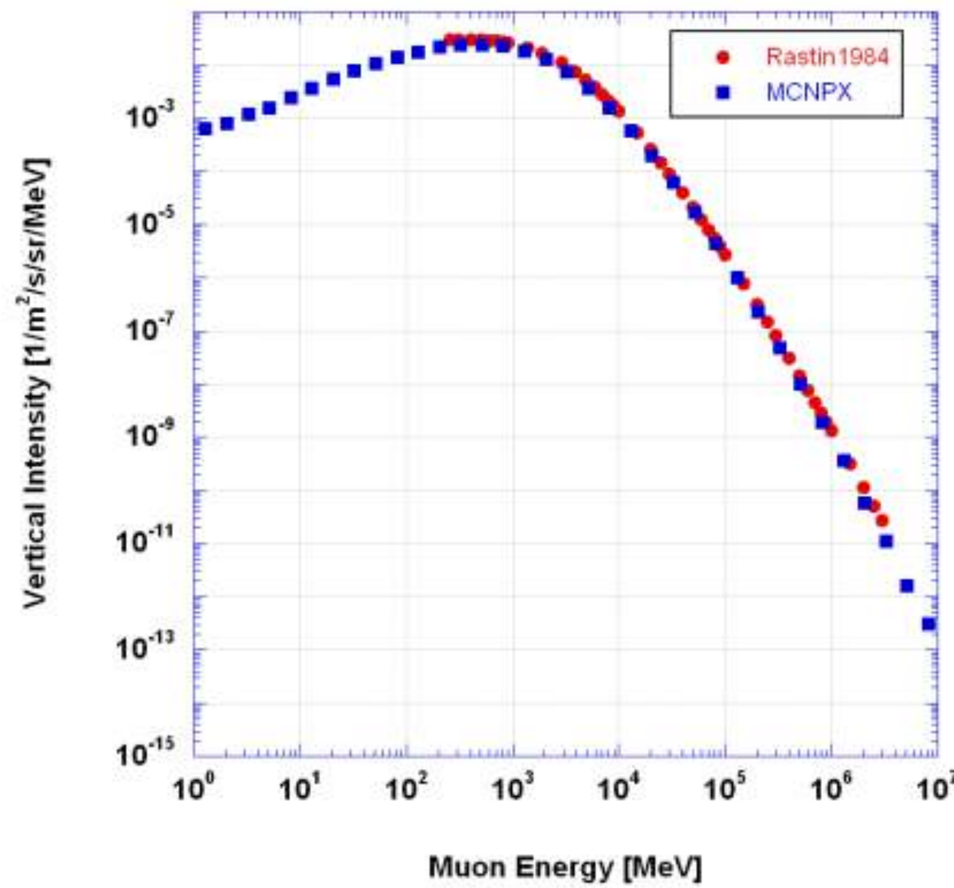


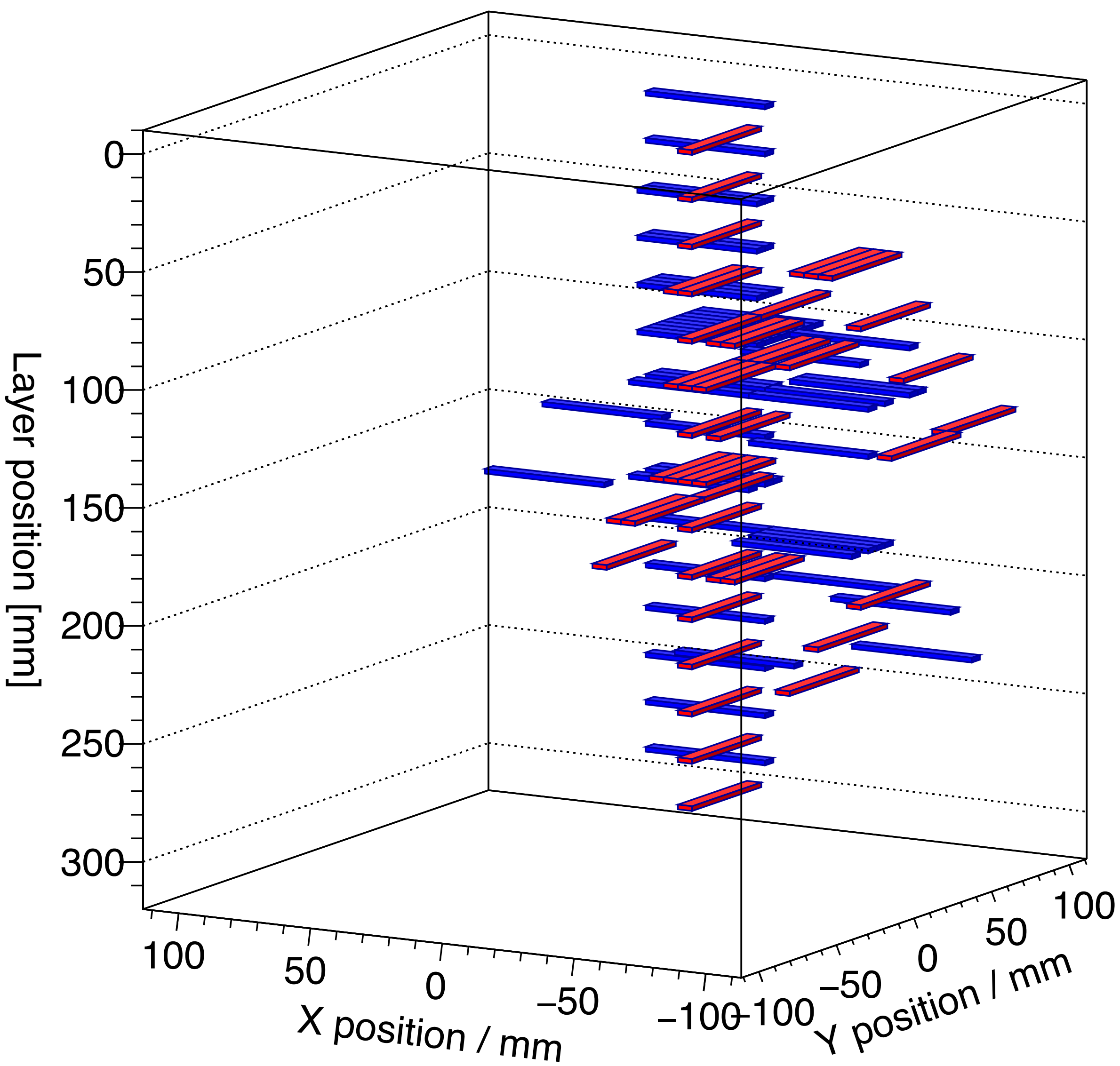
Figure 4: MC-generated muon spectrum and data measured at sea level.

C. Hagmann, D. Lange, D. Wright
INIS, Vol 38 No 40 (2007)

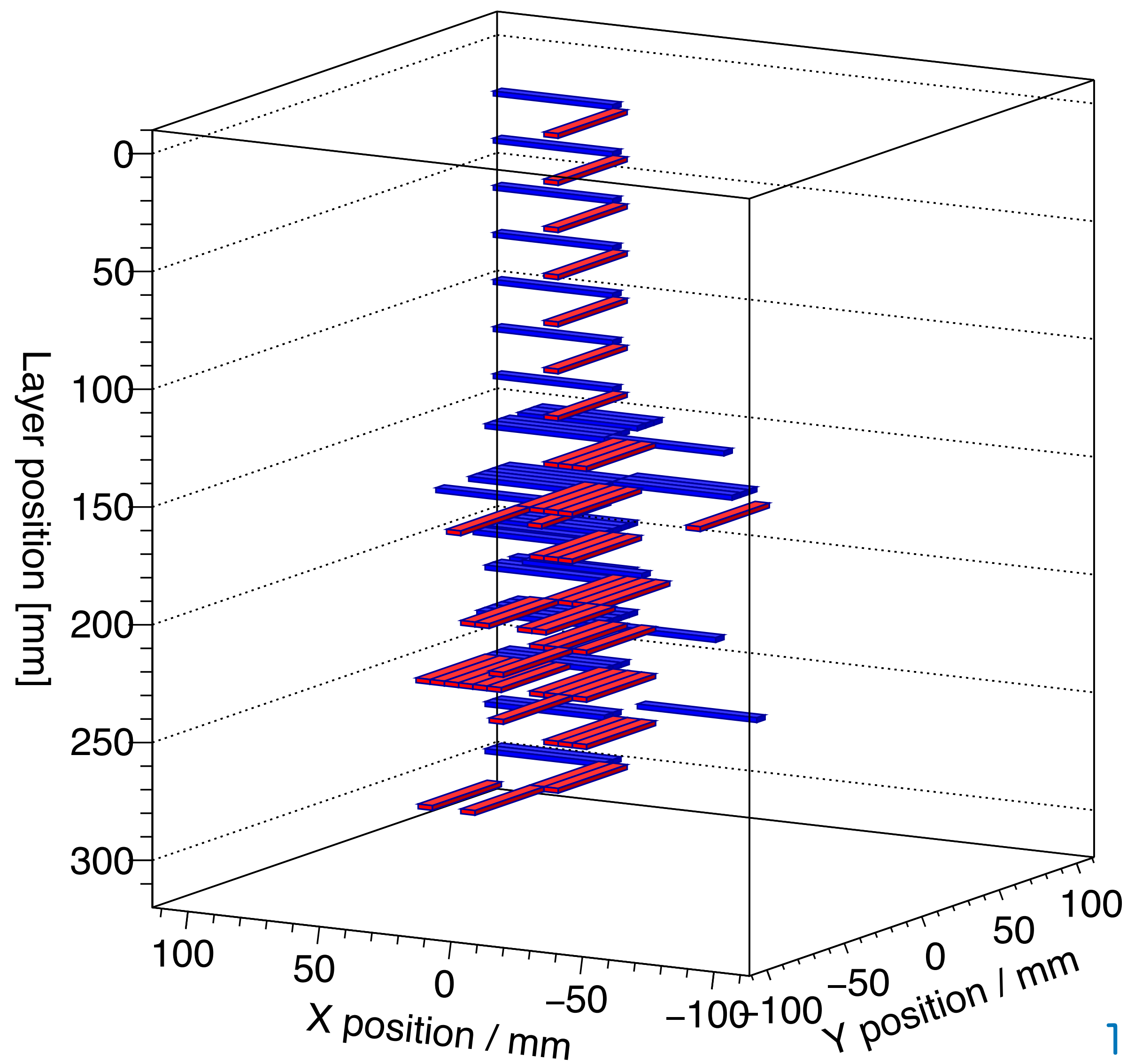
Results

- Shower events are searched for with the same algorithm
- Further analysis will be done
  - Accumulate the statistics
  - Further comparison with data and simulation

EventID : 1



EventID : 3



Summary

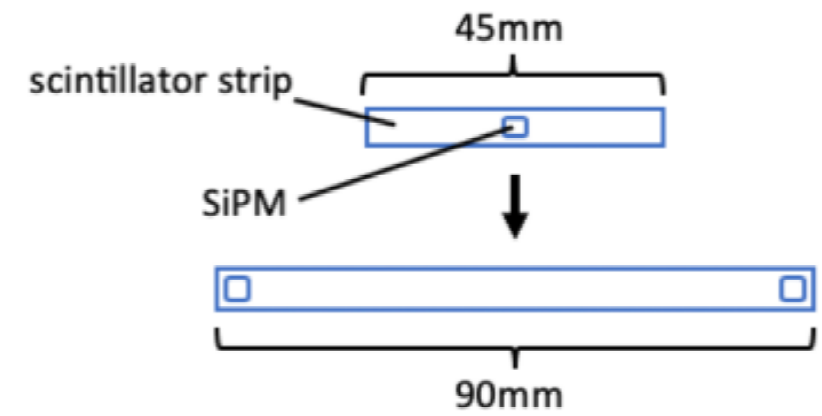
- LED-based calibration for Sc-ECAL prototype was done
  - Inter calibration of high-gain and low-gain for electronics
    - Gain and CTAP probability obtained for all channels
    - Some differences between 3 method, because of the difference of signal waveforms and DAQ method
  - Gain and CTAP calibration
    - Gain and CTAP probability obtained for all channels
    - Gain has 2 types due to the difference of the pixel-pitch of SiPMs
    - CTAP probability is reasonable compared to the catalogue value, and can be used for the energy reconstruction and saturation correction
- Shower analysis
  - CR shower study to evaluate the performance of Sc-ECAL
  - Further analysis such as comparison with simulation is on going

Backup

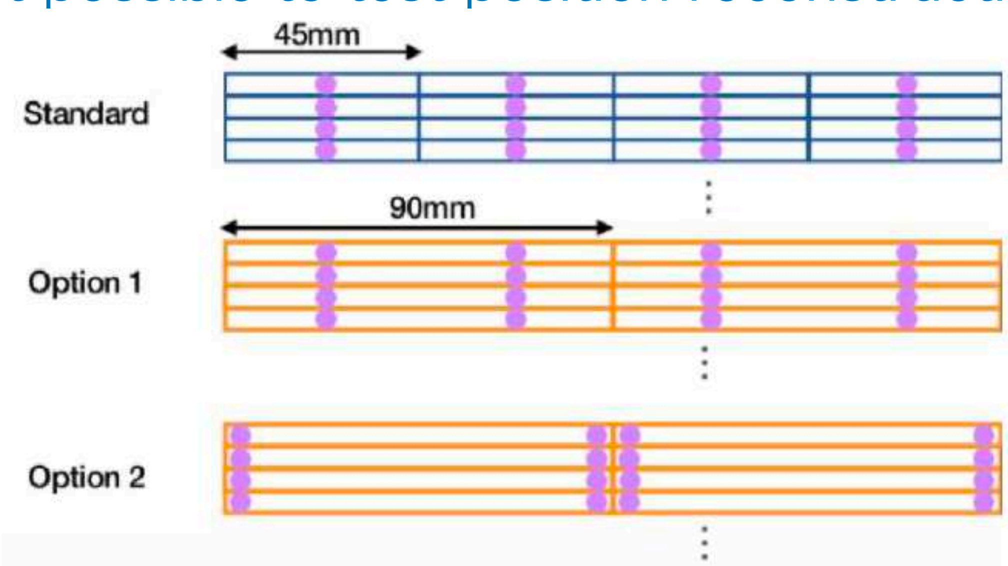
Double SiPM readout

(See 15aSE-8)

- **Readout by 2 SiPMs at strip ends**
- Twice longer strip (L=90mm) to keep the number of SiPMs
- Possible advantages
  - Eliminating noise by taking coincidence
  - Higher light yield by summing 2 SiPM readouts
  - Even lower light yield for each SiPMs (→less saturation)
  - Position reconstruction by charge and/or timing difference between two readouts (→ reduce ghost hits)



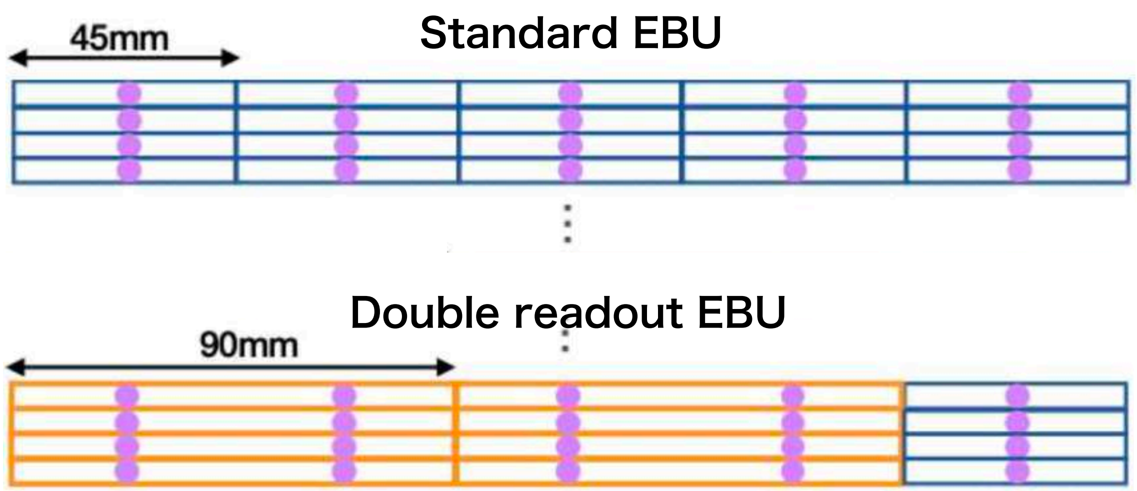
- **Two detection layers with double readout are installed in the prototype**
  - SiPMs in the middle of the strips instead of the strip ends
    - To be compatible with standard EBU PCB design
    - Not possible to test position reconstruction

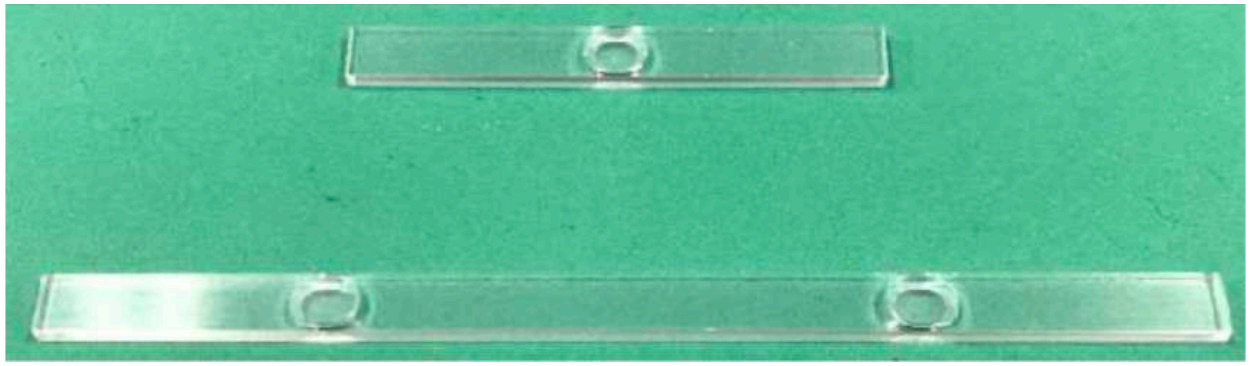


SiPM position in double readout strip

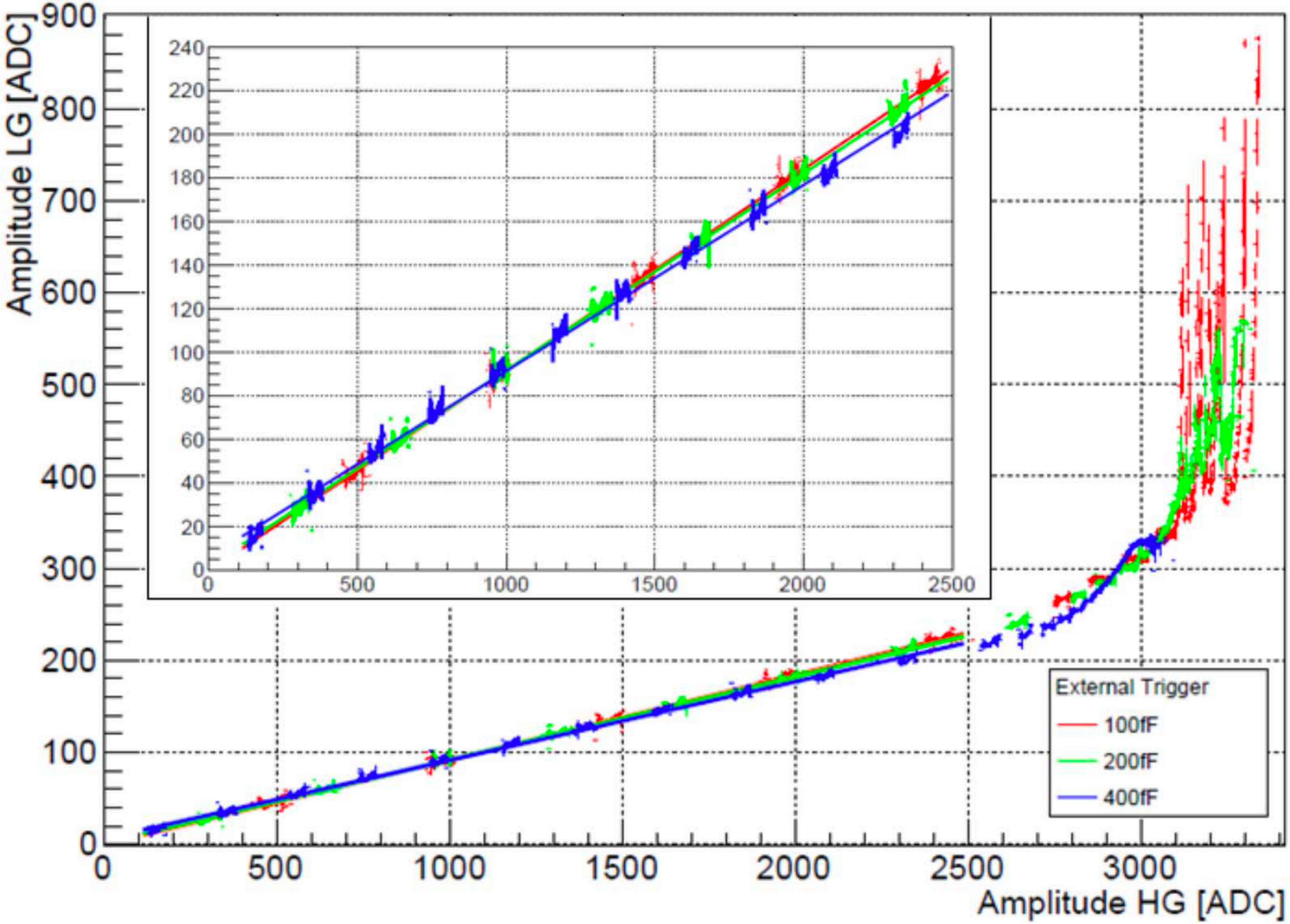
Production of scintillator strips for double readout layer

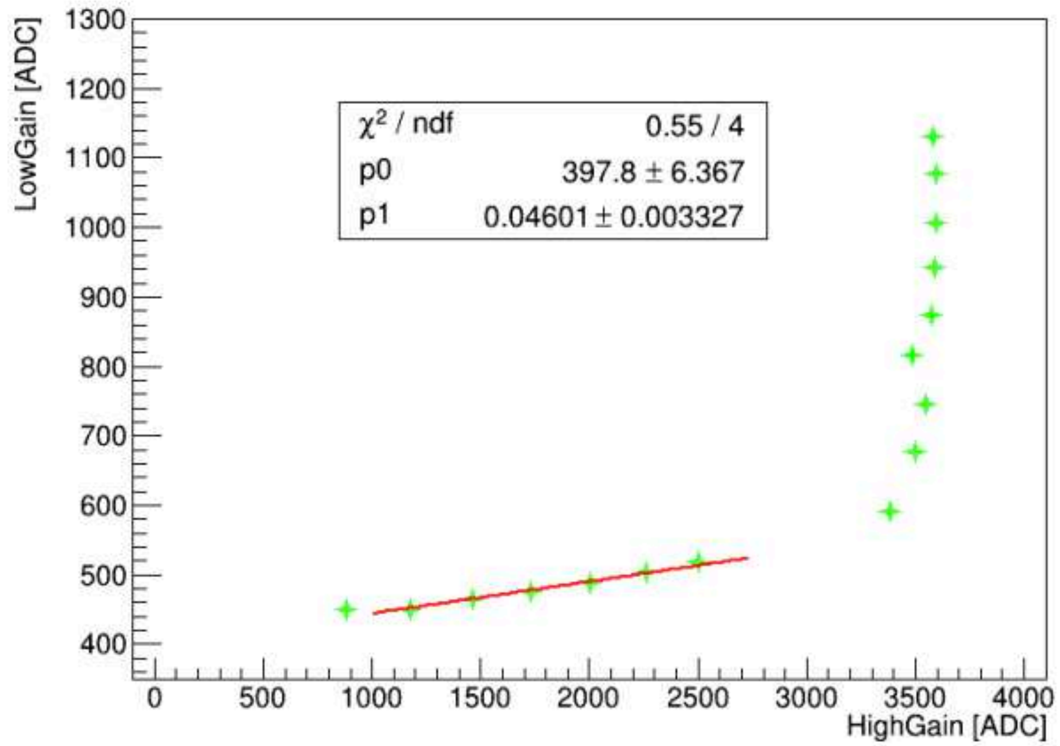
- **200 × 90mm strips** and **100 × 45mm strips** were produced
  - 5 rows of 45mm strips at 1 line for the standard configuration
  - 90mm + 90mm + 45mm at 1 line for the double-readout layer
- Scintillator strips produced by injection moulding
  - Injection moulding would be the only possibility for the large scale production
  - Lower light yield compared to standard PVT scintillator
  - Production of large 2mm-thick plate by injection moulding → machining (strip shape + cavity)



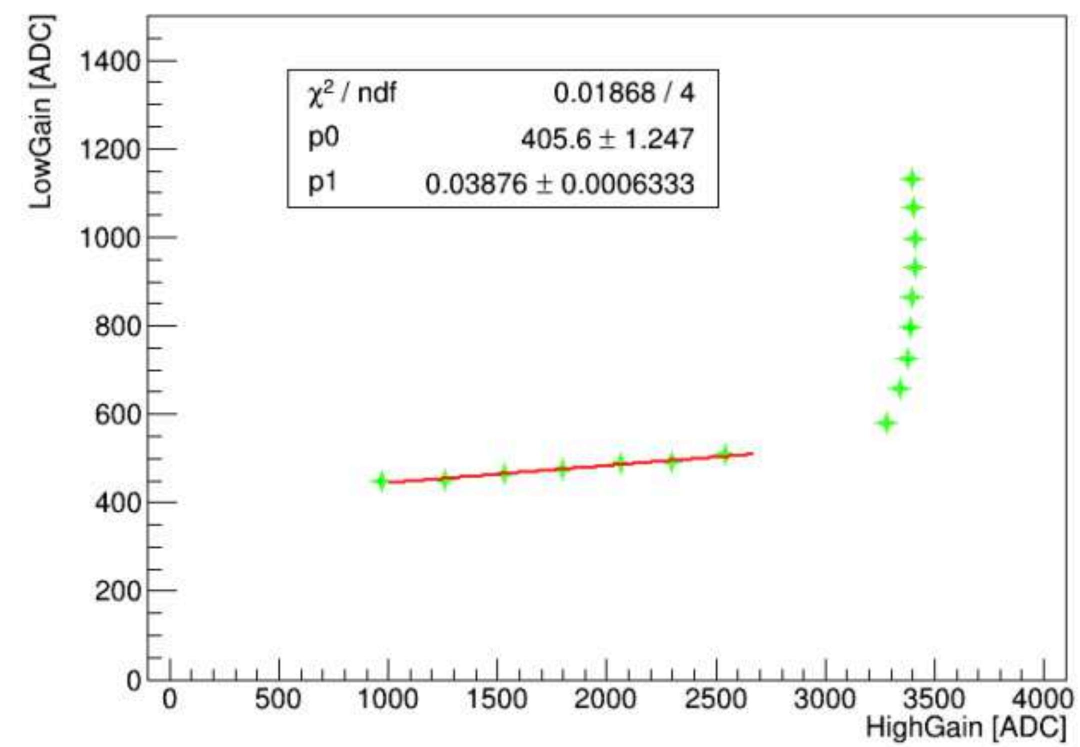


LG HG inter-calibration

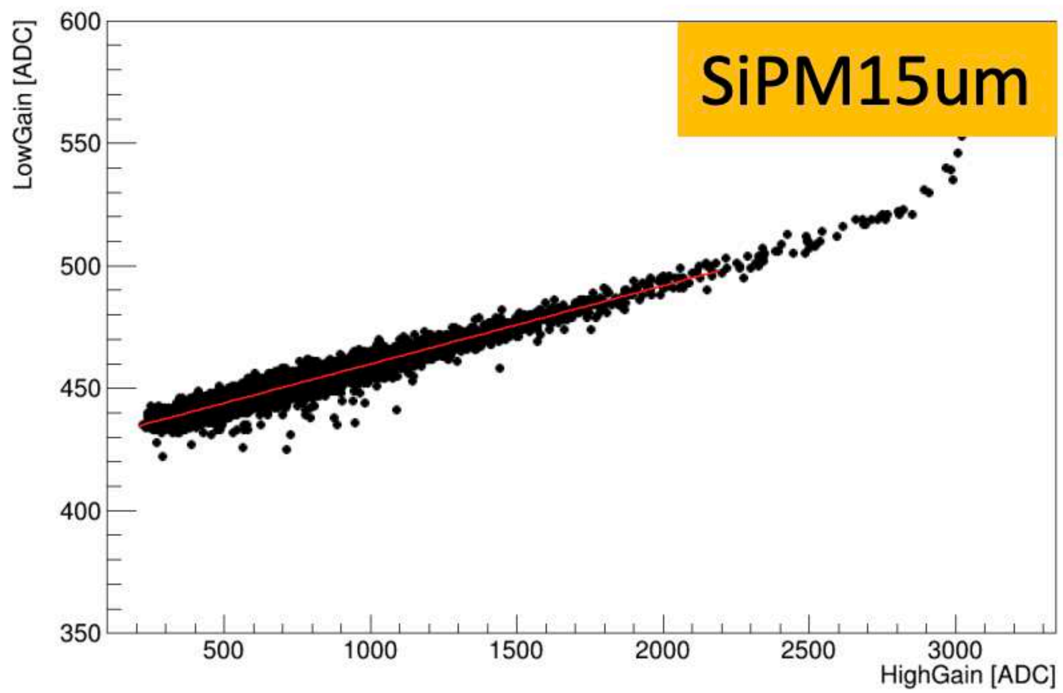


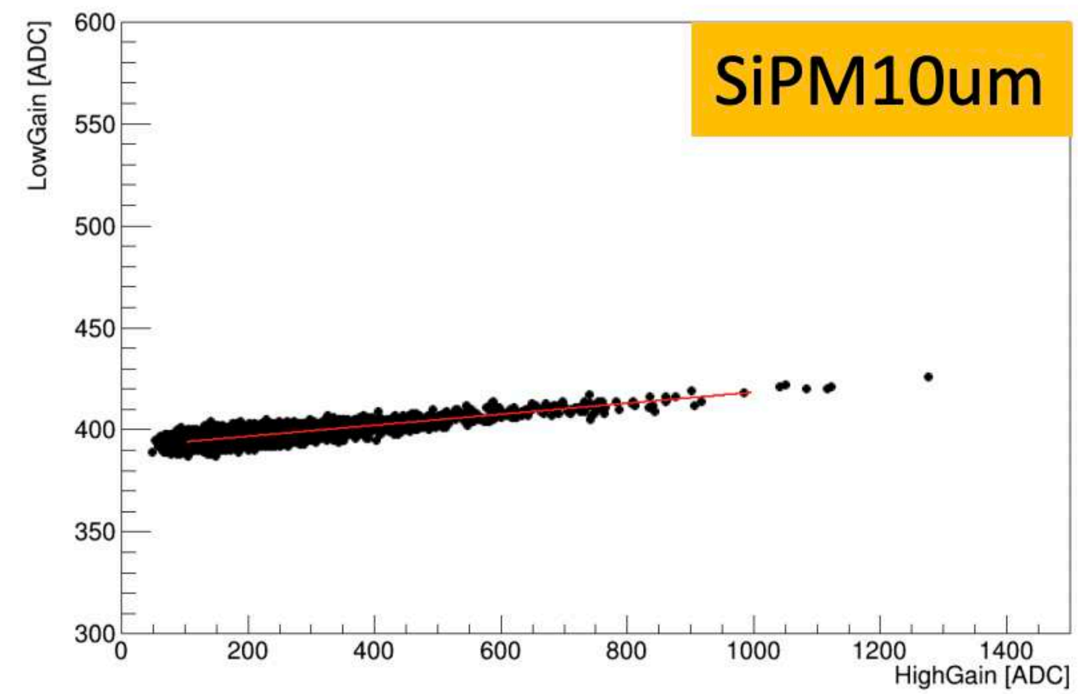


Layer0_Chip0_Chn0



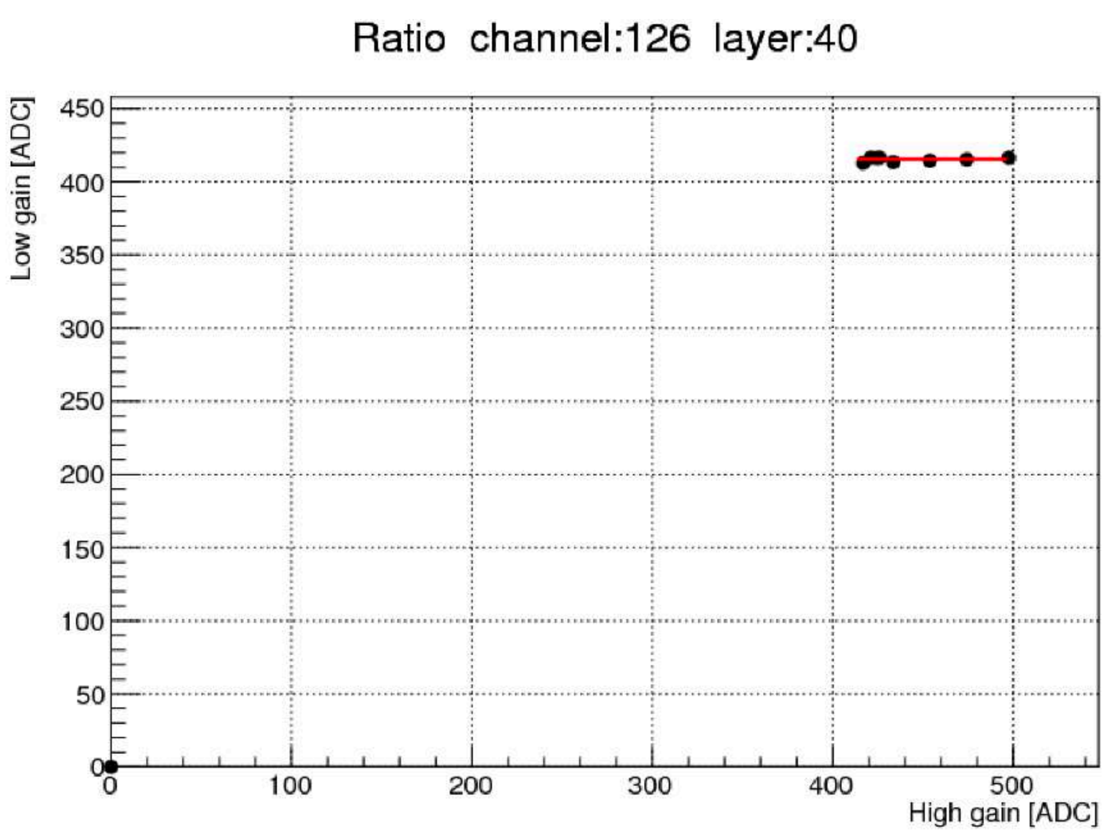
Layer4_Chip0_Chn5

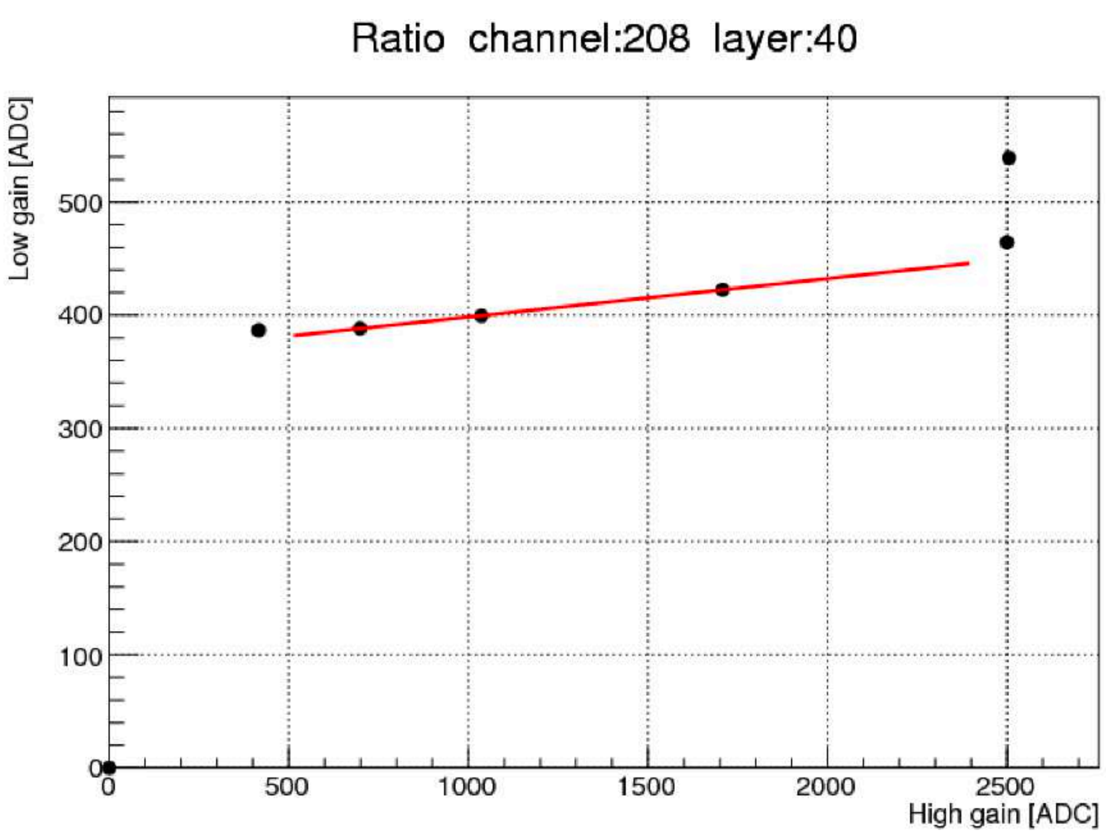




Fitting fault

- Some channels cannot catch the enough light yield for LED inter calibration
    - SiPM cannot catch the light from LED due to miss-alignment, broken LED or SiPM
- Some channels cannot have enough fitting points
    - Interval of LED scan is minimum
    - Overlapped region of high-gain and low-gain is narrow
    - LED scan cannot include enough points at the overlapped region





Fitting fault

- Some channels cannot be obtained the probability of CTAP
  - If gain is small, the separation of peaks of 0, 1, 2 photons is difficult