ILC-JP detector seasonal meeting
ScW-ECAL group report

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The University of Tokyo

Contents

- Sc-ECAL technological prototype
- Strip study
- Sc-ECAL simulation study
- Saturation study
- Dual readout with homogeneous material
- Summary and prospects

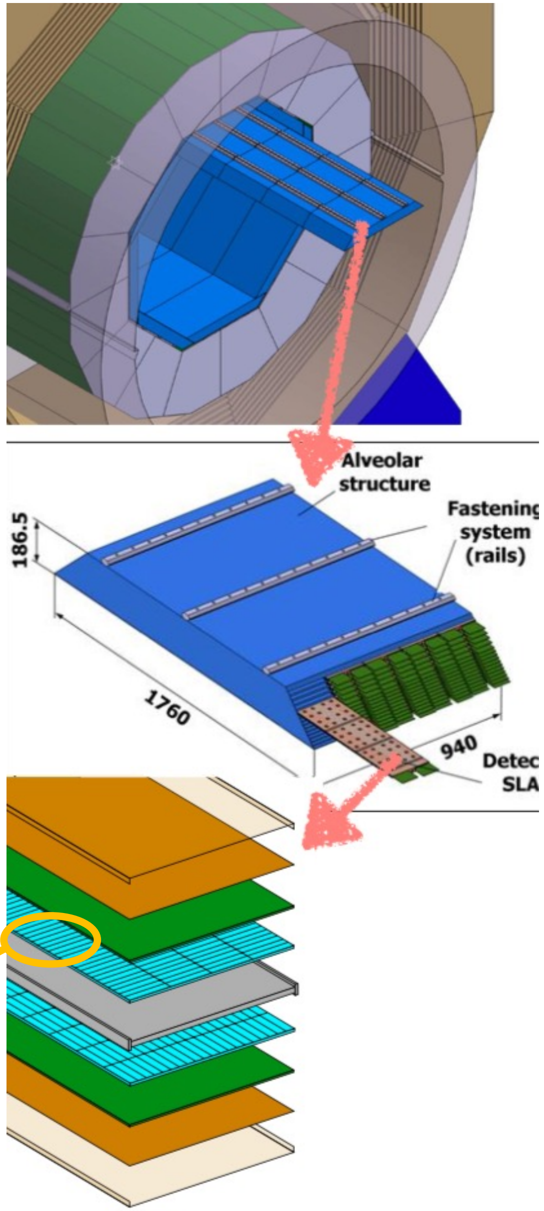
Sc-ECAL

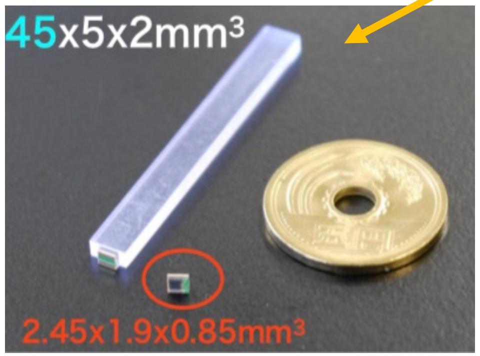
- Scintillator Electromagnetic CALorimeter (Sc-ECAL)

  ➡ Technology option of EM calorimeter for ILC and CEPC
  ➡ Based on scintillator strips (5 x 45 x 2 mm^3) readout by SiPM

- Virtual segmentation : 5 x 5 mm^2 with strips in x-y configuration

  ➡ # of readout channels significantly reduced ($10^8 \rightarrow 10^7$)
  ➡ Retaining performance comparable to real 5 x 5 mm^2 segmentation





Sc-ECAL technological prototype

- Technological prototype for Sc-ECAL has been constructed as a joint effort by R&D groups for ILC-ILD and CEPC-ECAL

  ➡ Full 32 EBU layers, total ~ 6,800 channels

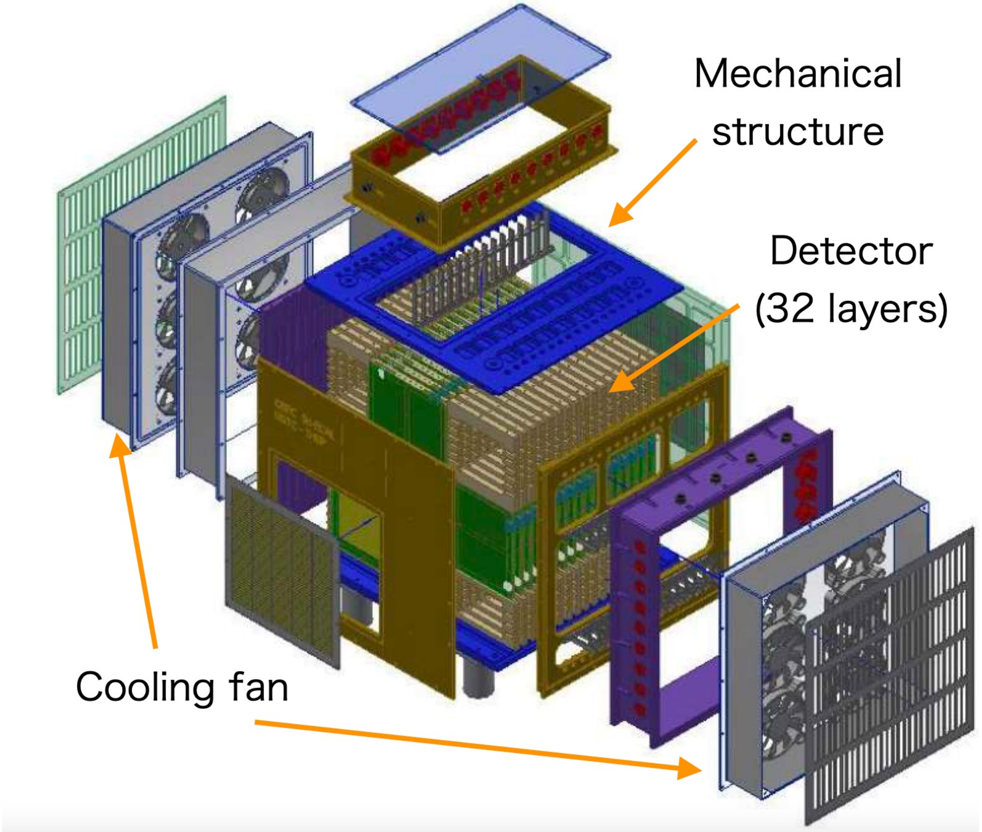
- Assembly was already done

  ➡ Two detection layers with double SiPM readout
  ➡ Two additional layers developed by Shinshu group

  ➡ Various calibrations in progress
  ➡ Tested with cosmic ray

- To be tested in beam

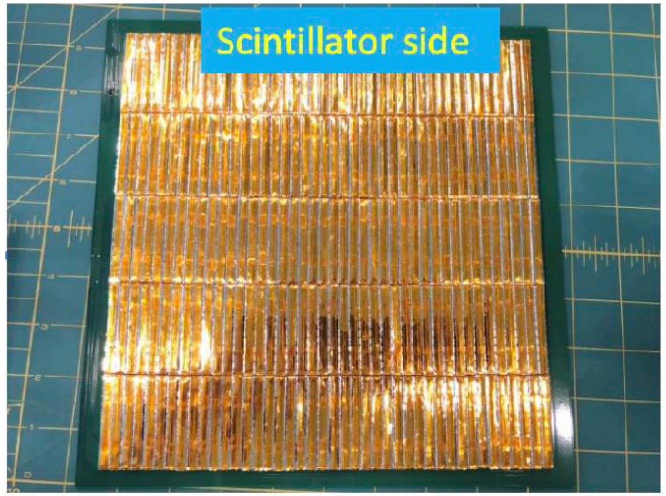
  ➡ DESY or IHEP

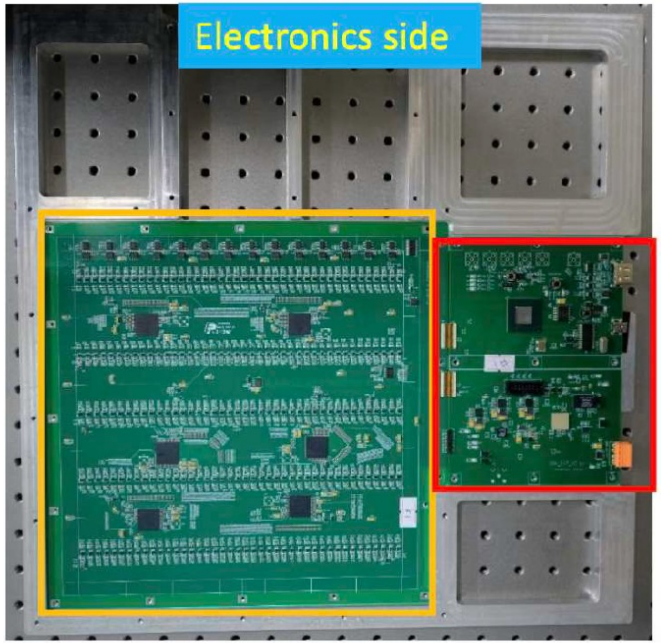


Sc-ECAL technological prototype

ECAL Base Unit (EBU)

- 210 channels readout with 6 SiPM operation chips (SPIROC2E) divided into 5 rows and 42 columns
- 5 x 45 x 2 mm^3 strips wrapped by ESR film are aligned
- Total layer thickness : 6 mm / layer
- Electronics calibration and SiPM operation voltage adjustment realized





	Active area	Pixel pitch	#pixel	#layer
S12571-010P	1×1 mm^2	10 μm	10000	24
S12571-015P	1×1 mm^2	15 μm	4489	6

Sc-ECAL technological prototype

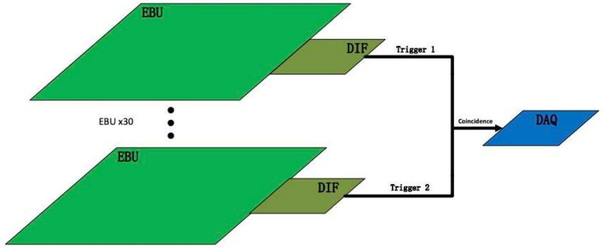
Cosmic ray test

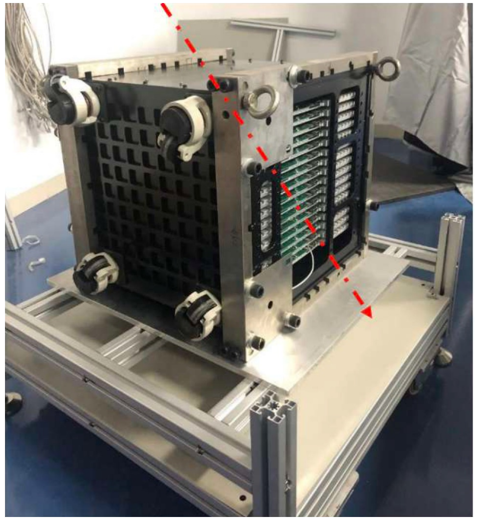
- Position resolution and cell-to-cell MIP calibration of prototype
- Long term test in 1.5 month

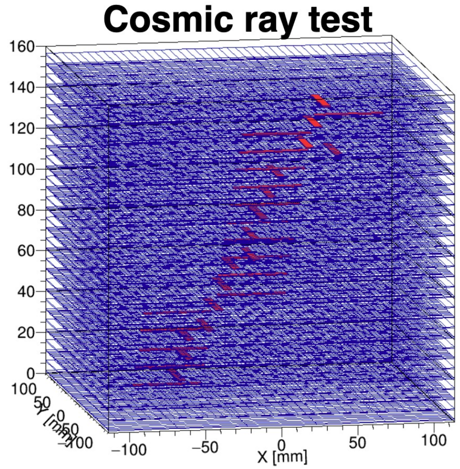
  ➡ Coincidence trigger of top and bottom layers
  ➡ Event rate : ~ 16 events / minute
  ➡ Collect ~ 2000 events at each channel

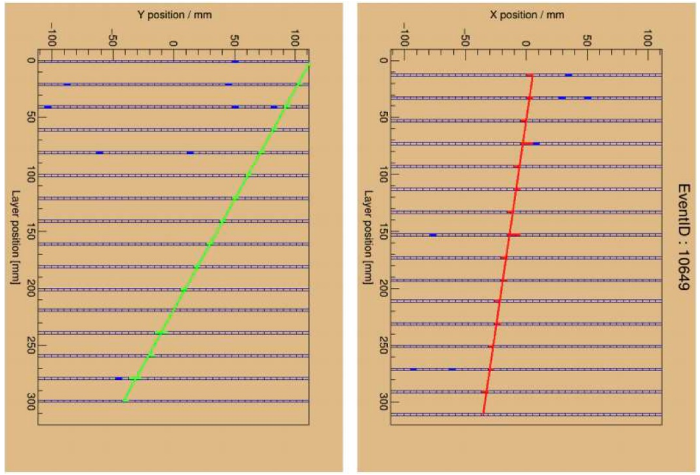
- Track finding and fitting were done

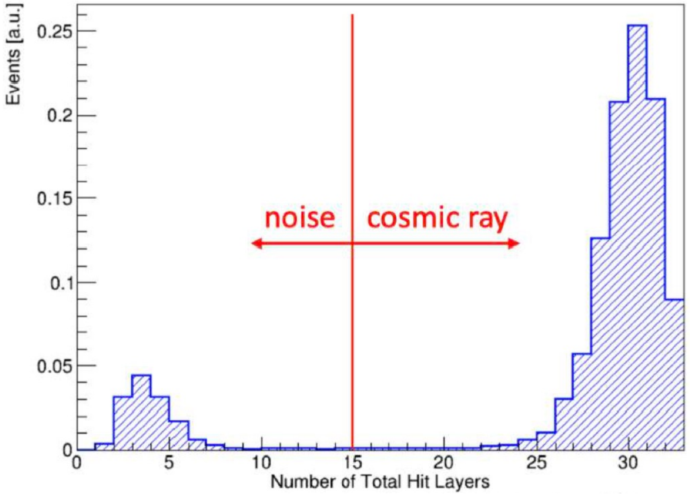
  ➡ A preliminary algorithm for some preselections was tested











Sc-ECAL technological prototype

- Obtained position resolution ~ 2 mm

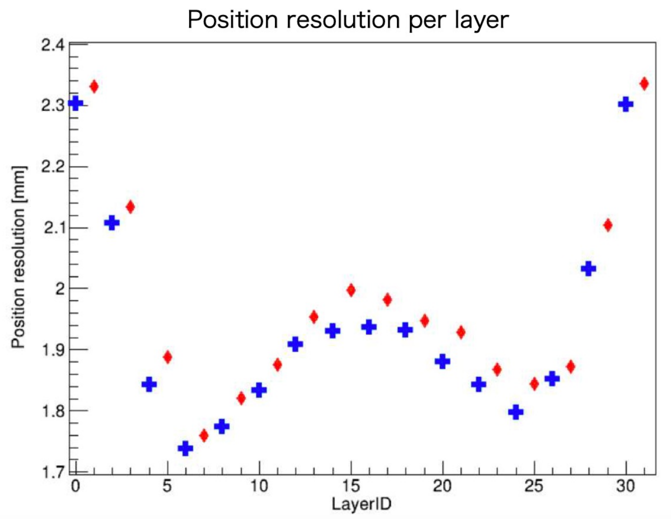
  ➡ Achieve the requirement for Sc-ECAL

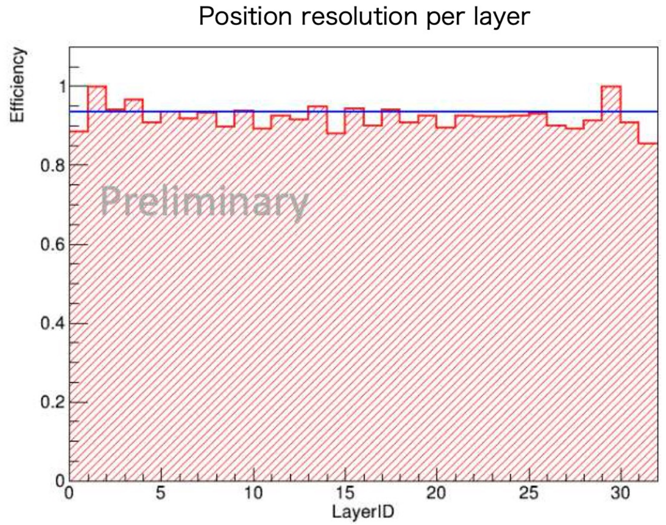
- Efficiency achieves 90 % for all layers

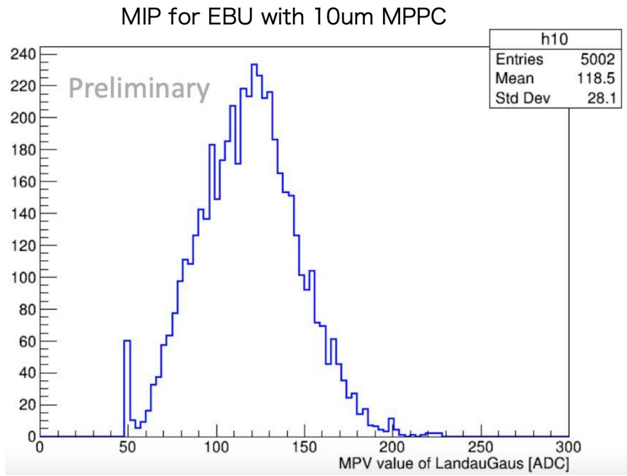
  ➡ Layer 1 & 29 are trigger
  ➡ Sensitive area is 93.5 %

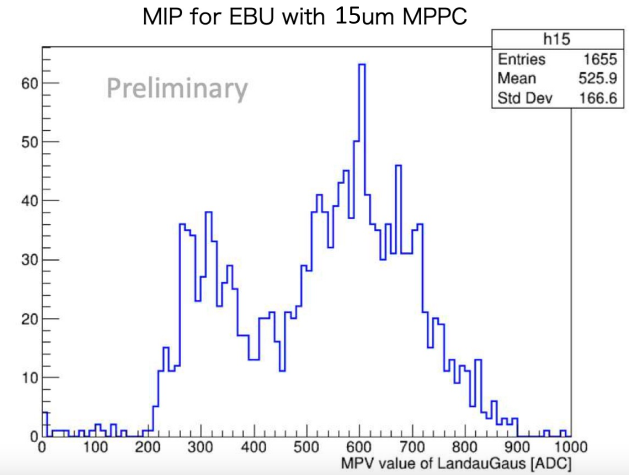
- MIP calibration

  ➡ Preliminary cell-to-cell MIP calibration succeeded
  ➡ MIP values widely spread

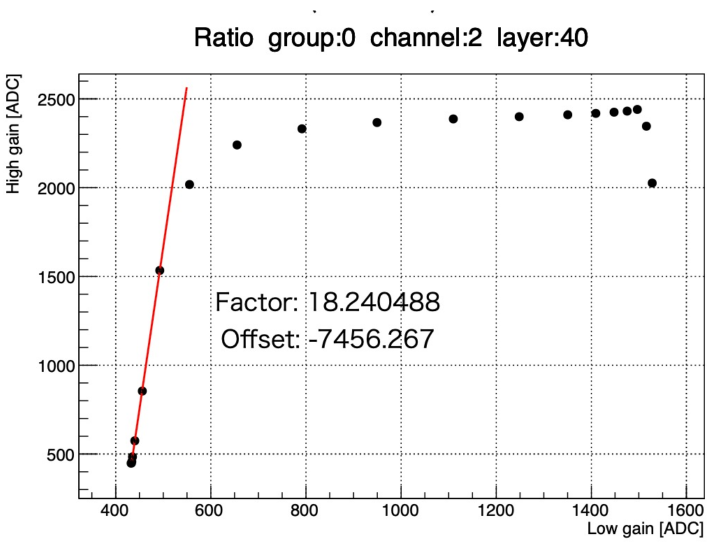








Sc-ECAL technological prototype

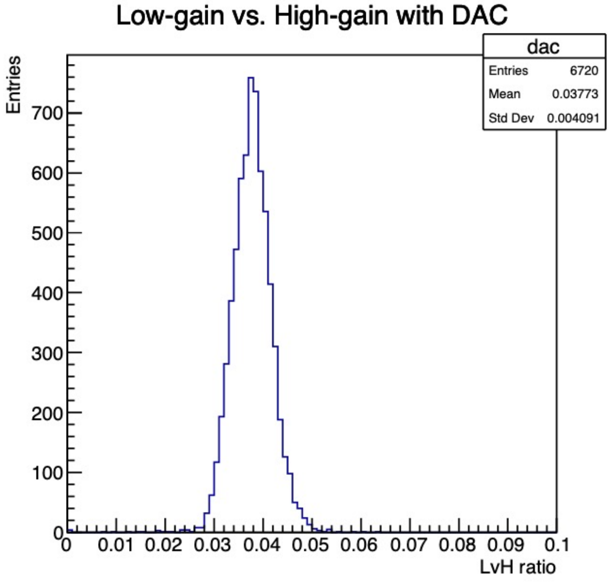


- Inter-calibration

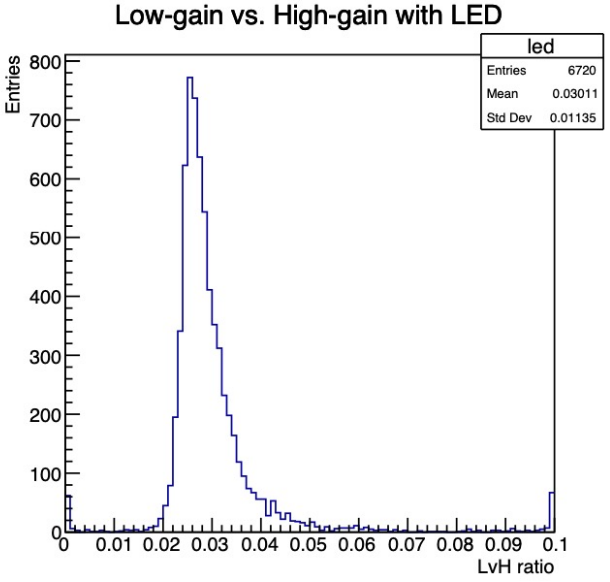
  ➡ SPIROC2E on EBU has low gain mode and high gain mode
  ➡ Check the ratio of low and high gain for calibration

- Two method for inter-calibration : LED, DAC

Using LED



Using DAC

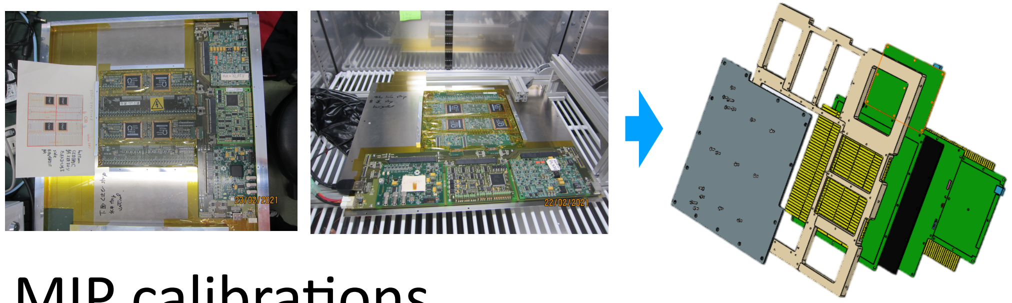


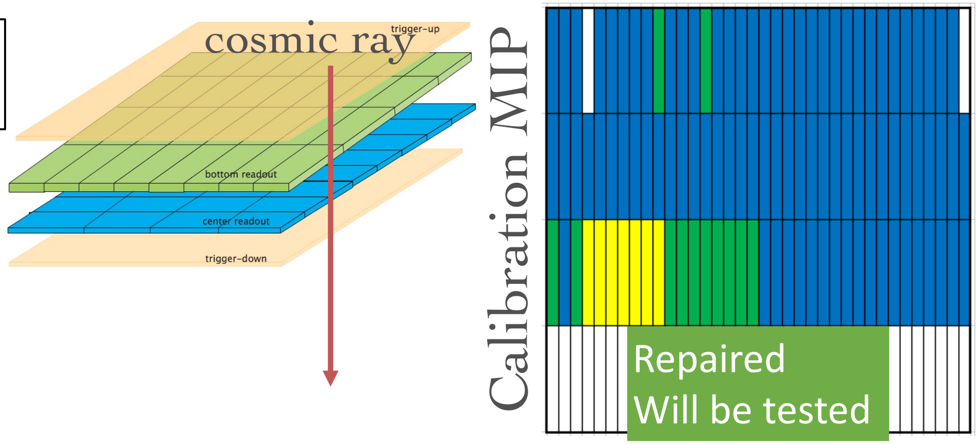
- There is a little difference between LED and DAC

  ➡ Under investigation

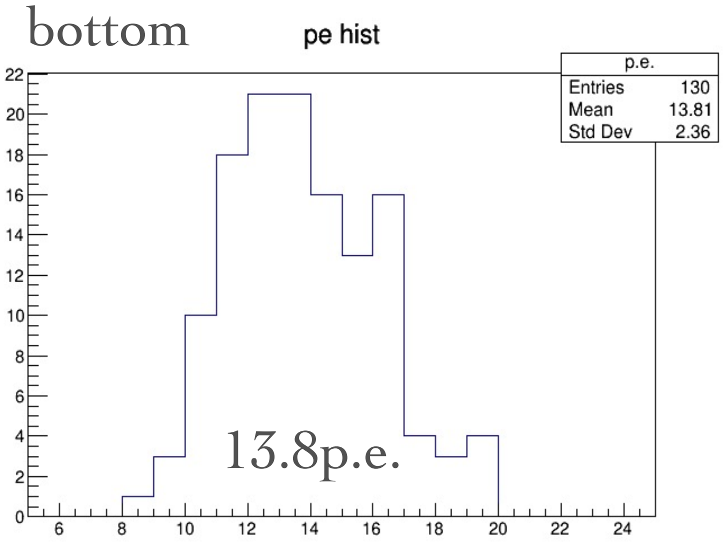
Sc-ECAL technological prototype Shinshu

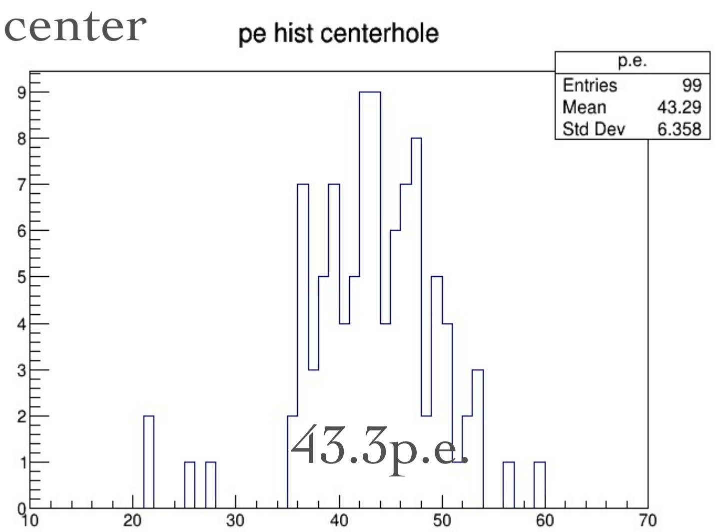
- Two layers with DESY EBUs and X Y configurated strips from Shinshu were implemented

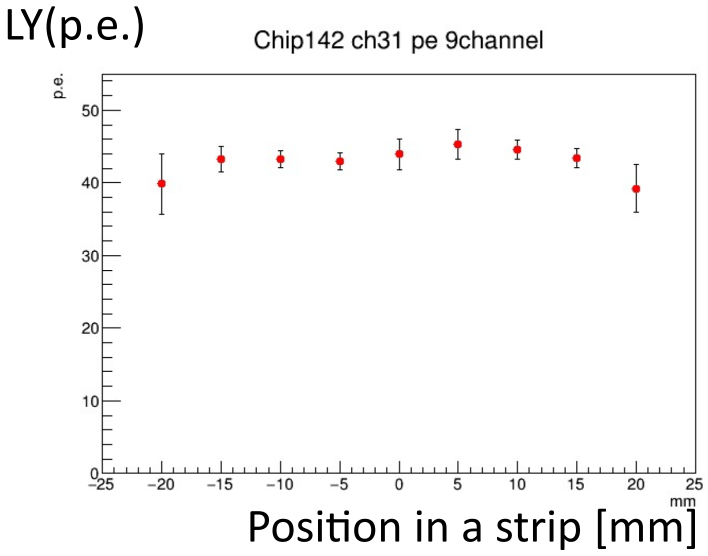




- LED and MIP calibrations
  ➡ Light yield : bottom types wedged strip
  ➡ Cosmic data are taken and showing a good uniformity in a strip



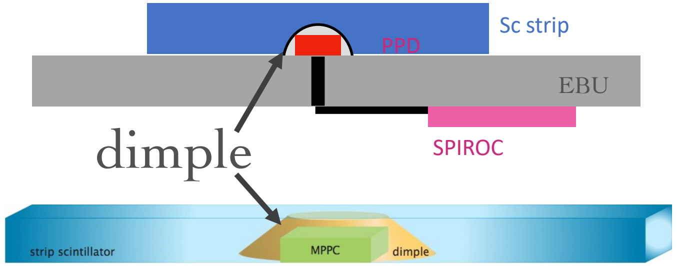


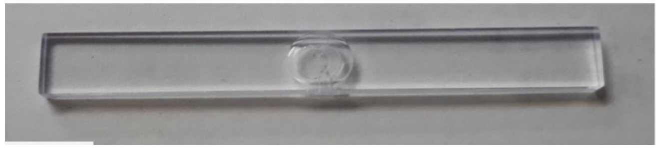


Strip study

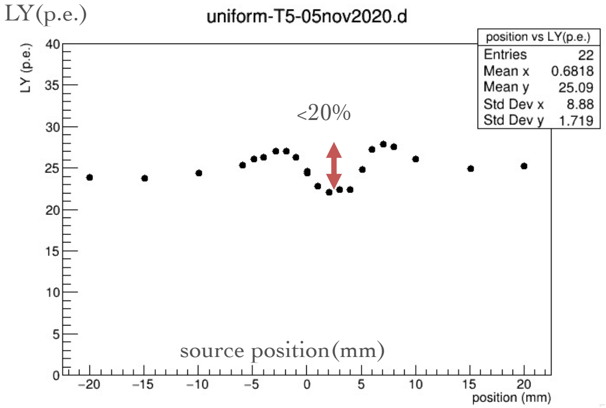
Optimization of dimple

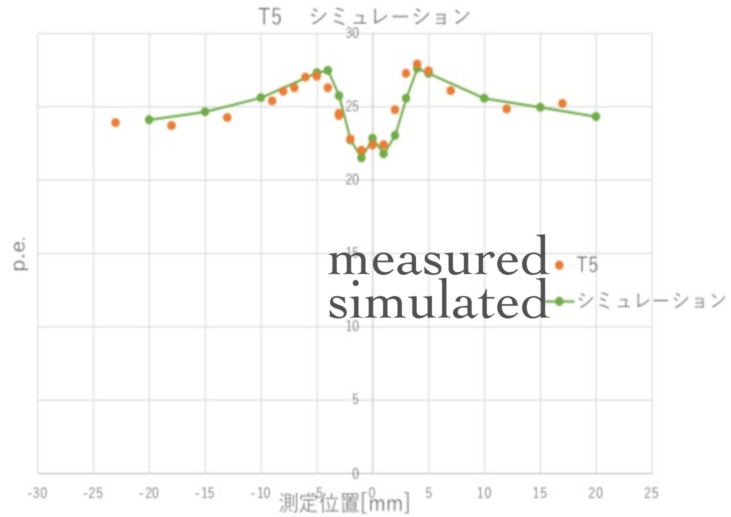
Shinshu

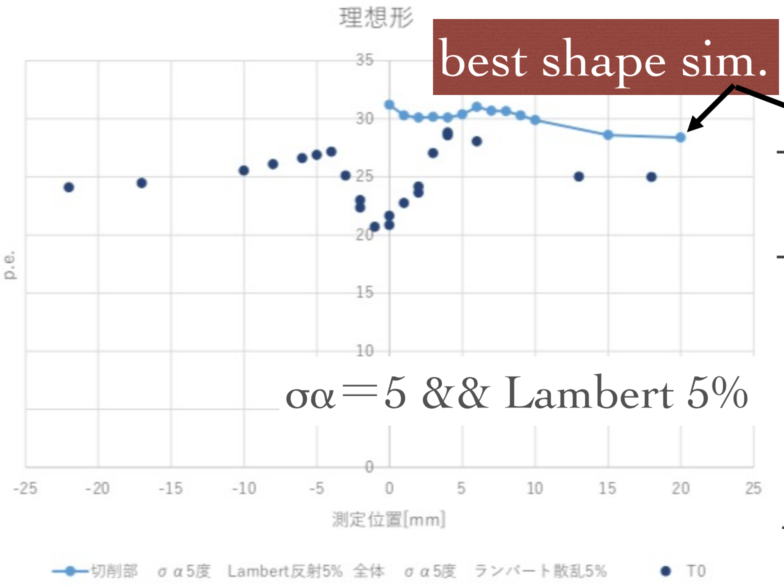


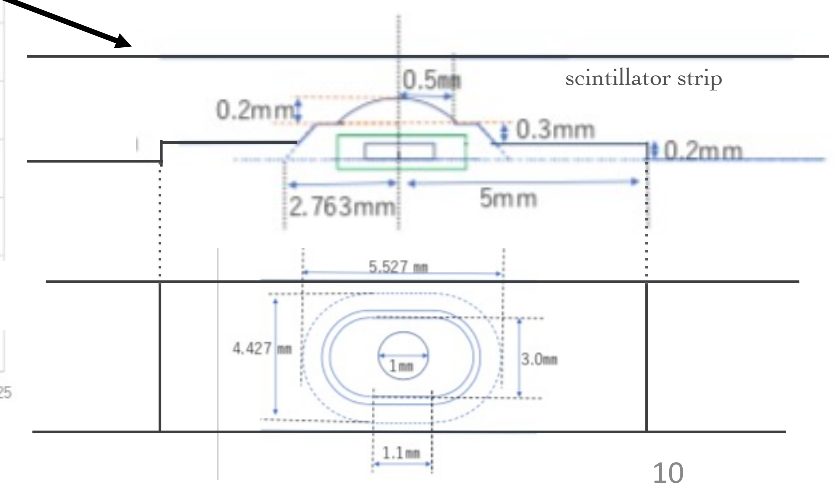


- Dimple shape
  - ➡ Current design has a dip and bump structure in uniformity
  - ➡ Simulation of light tracing indicates better solution of good agreement with measurements
- Predicts better shape of dimple ➡ will be tested with prototype









Study on scintillator strip production

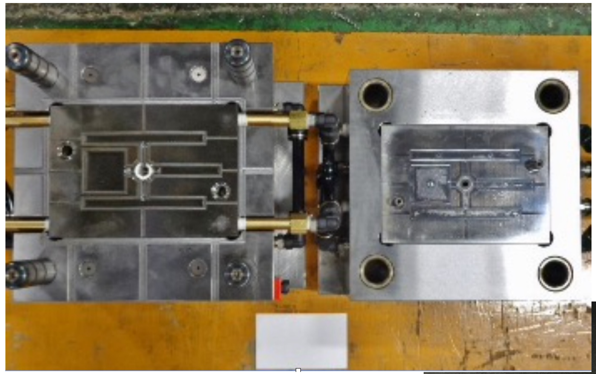
Shinshu, Tokyo

Test of scintillator strip production using dedicated metal mould

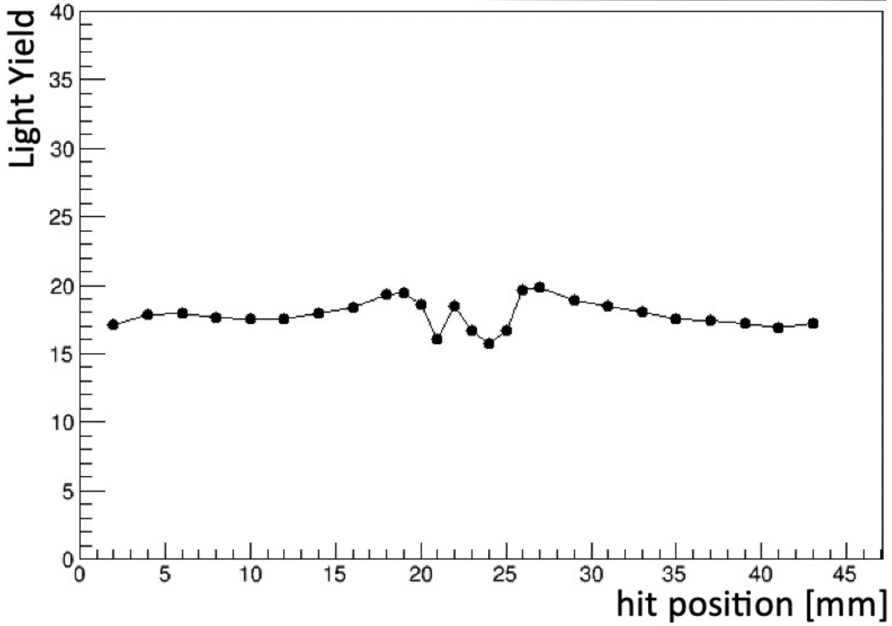
- Suitable for mass production in terms of cost

- Position dependence of light yield was tested

➡ The uniformity is better than EJ-212 strip
➡ Lower light yield (~18 p.e.) than previous injection molding strip (~23 p.e.) → 20 %
➡ Under investigation



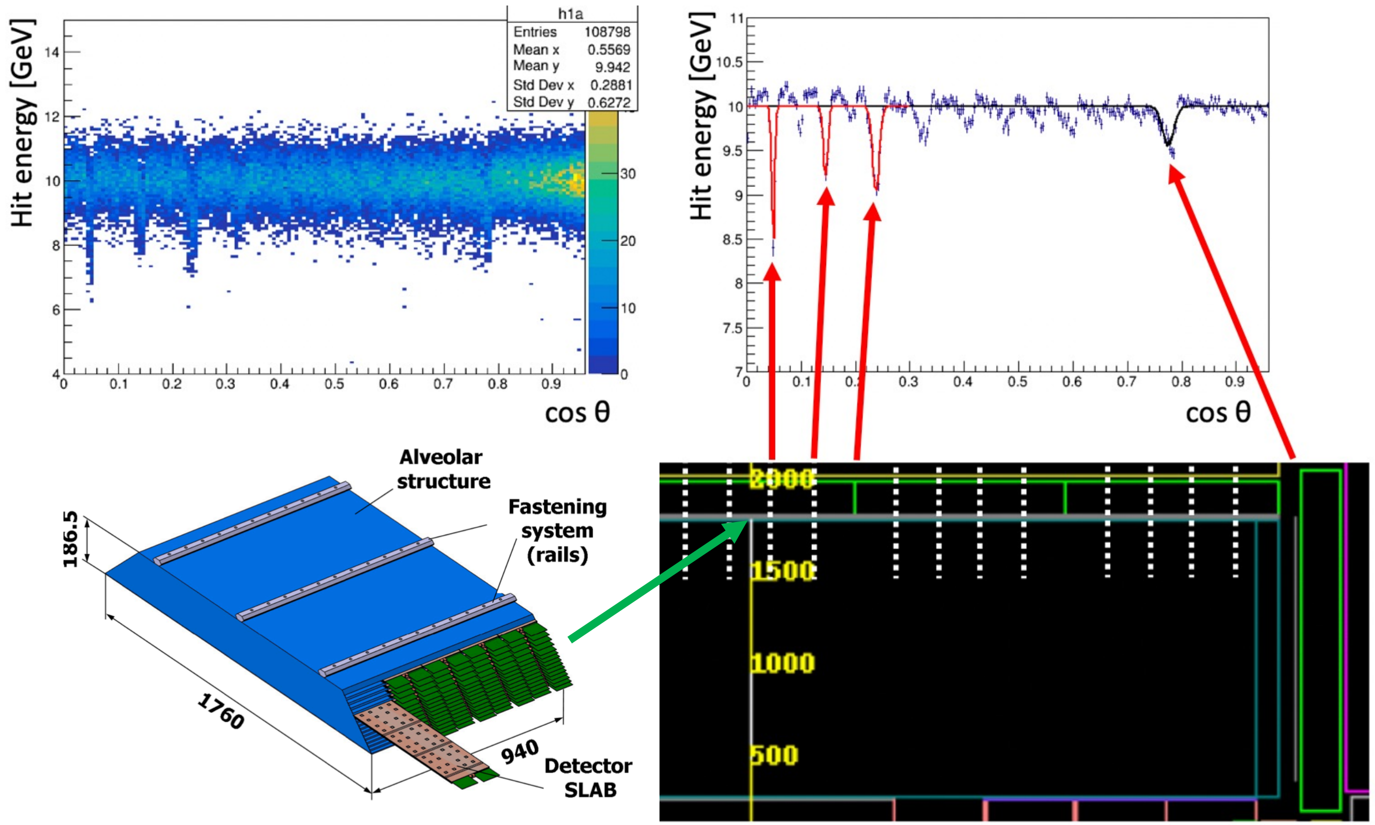
Dedicated metal mould



Sc-ECAL simulation study   Tokyo

- ILD simulation for Sc-ECAL performance study

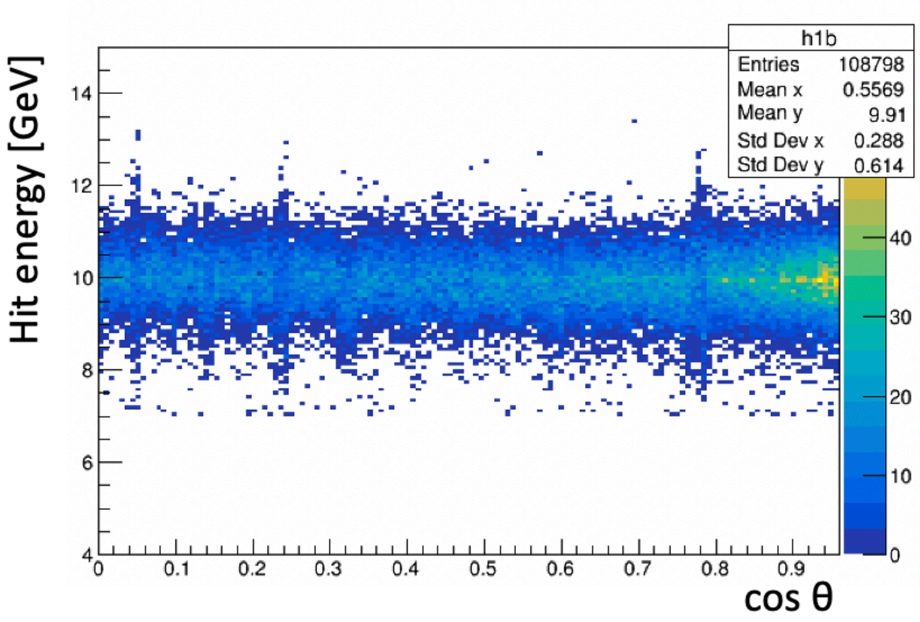
  ➡ Processor for modification of the hit energy reduction due to gaps between ECAL module



Used simulation tool : DD4hep

ilcsoft version : v02-01

Detector model : ILD_l5_o3_v02



Sc-ECAL simulation study

Tokyo

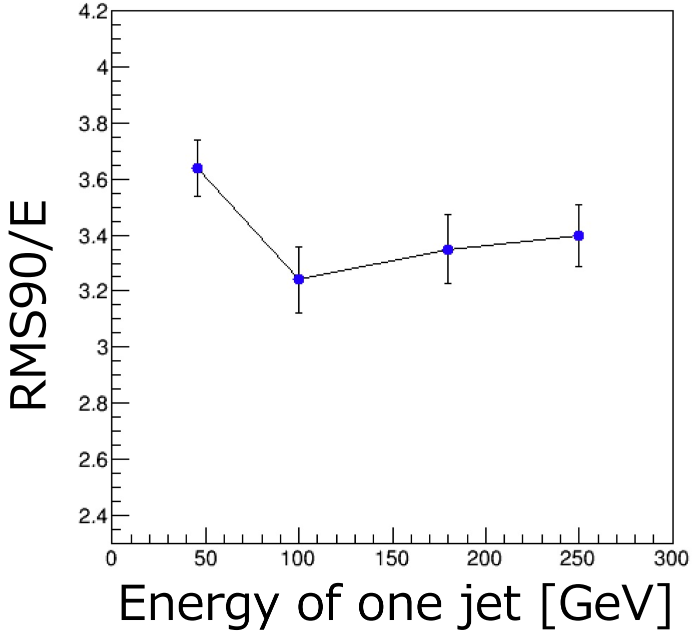
- Jet Energy Resolution was calculated with this gap modification effect

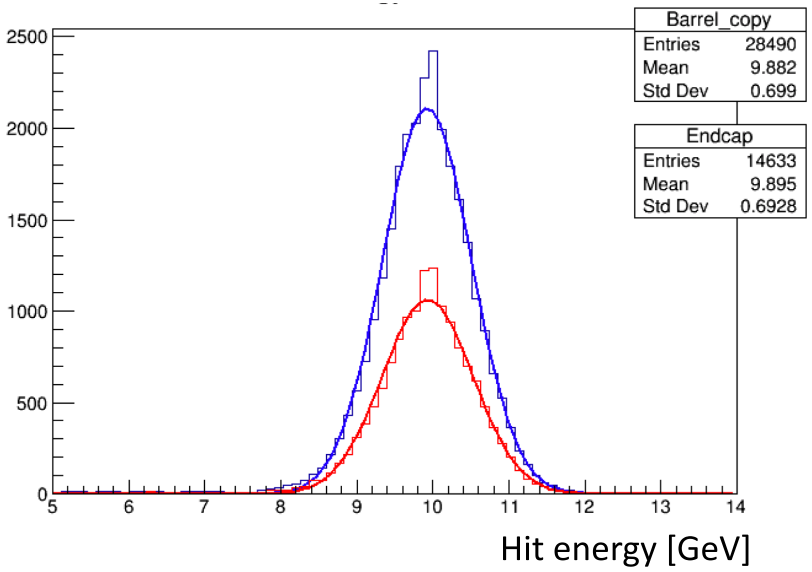
  ➡ It is consistent to results in previous study
  ➡ But, there is a strange peak at the target (true) energy in the hit energy histogram

  ➡ The processor should be updated

- Implementation of new processor is ongoing

  ➡ Hit position dependence of light yield in a strip
  ➡ Double SiPM readout effects
  ➡ Gap between strips





Saturation study Tokyo

- SiPM signal saturates for many photons due to limited number of pixels

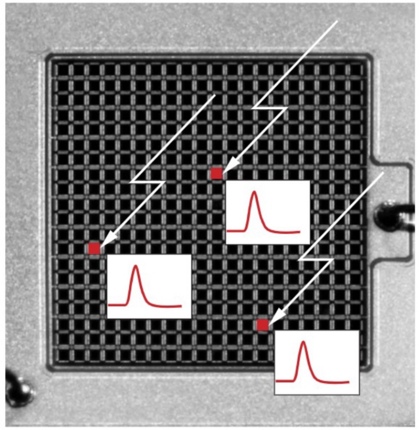
  ➡ Proper correction for SiPM saturation is crucial for Sc-ECAL for ILC

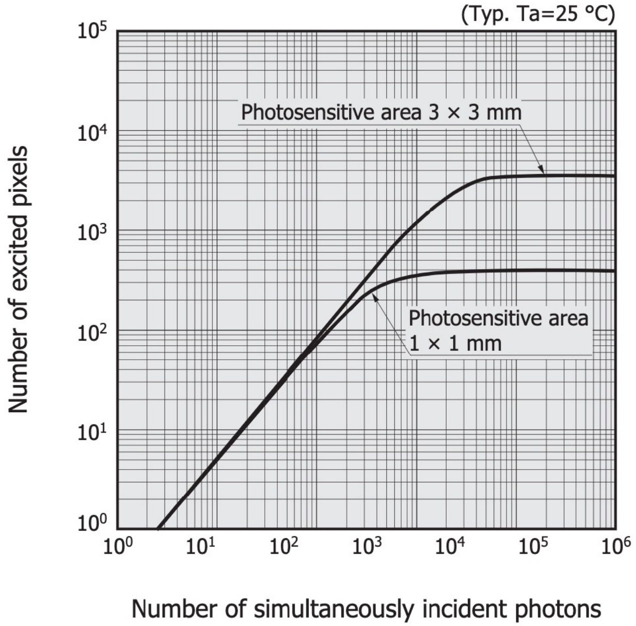
- This saturation curve is affected by scintillation emission time constant and SiPM recovery time

  ➡ Time constant of scintillation light (2.4 ns) is not negligible compared to the SiPM recovery time (few ns)

  ➡ Over-saturation, detecting more photons than number of pixels, can occur

[Figure 2-2] Image of MPPC's photon counting





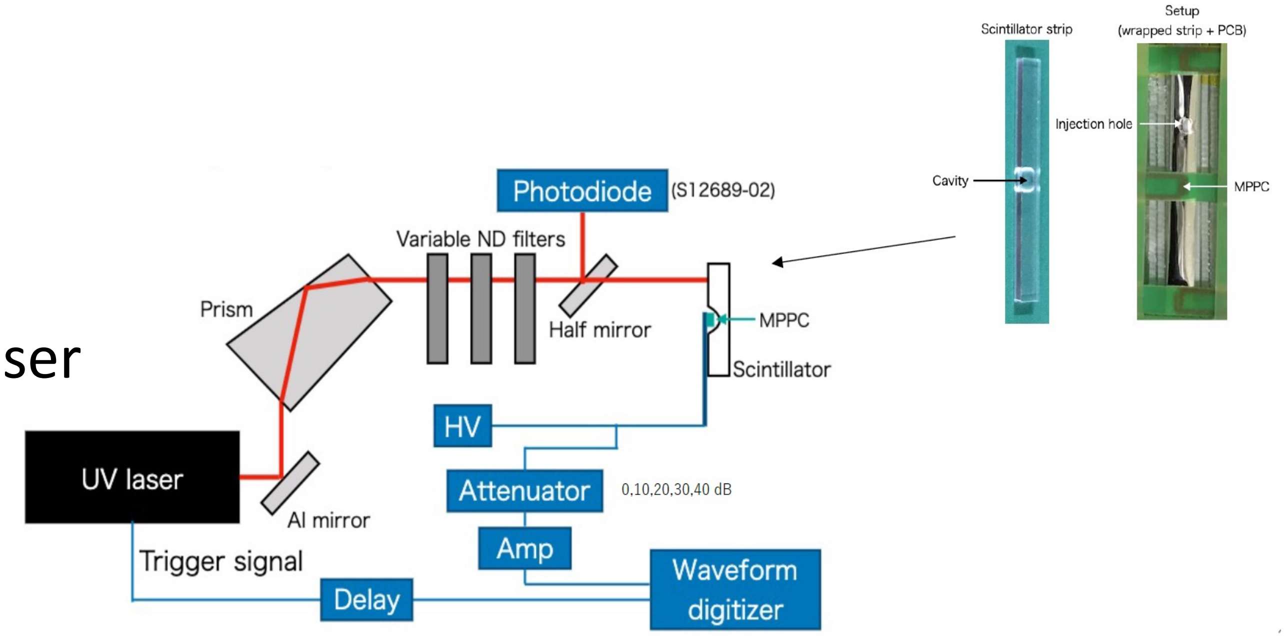
Hamamatsu Photonics K.K. Opto-semiconductor Handbook

- We propose to measure SiPM saturation curve with scintillator light excited by injecting UV light

Saturation study

Tokyo

Previous experimental setup



- Excite scintillation light with fsec UV pulse laser
  ➡ 5 x 45 x 2 mm^3 scintillator strip (EJ-212), MPPC S12571-015P/S14160-1315PS
  ➡ Incident UV light intensity is monitored with photodiode
  ➡ Signal attenuators are used to avoid electronics saturations

- Possible issues on this setup

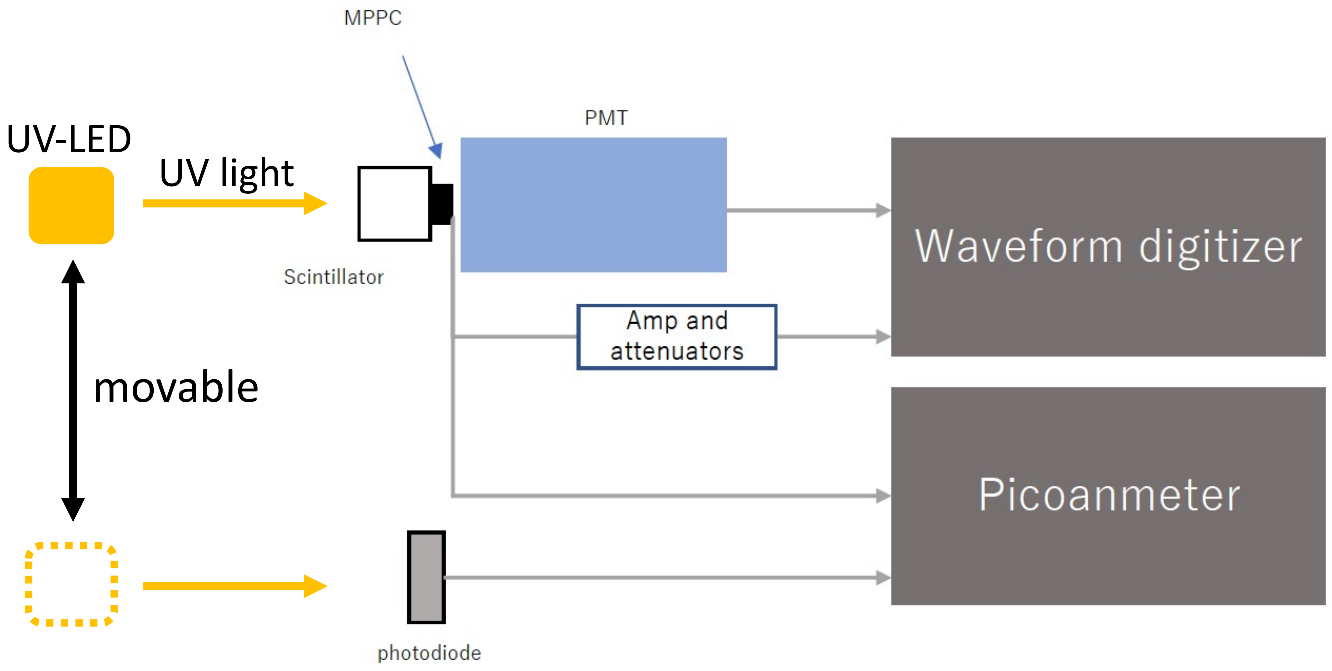
  ➡ The signal waveform changes as UV laser intensity changes due to attenuator → affects the estimation of p.e.
  ➡ Need to check if excited scintillation light is proportional to intensity of UV laser

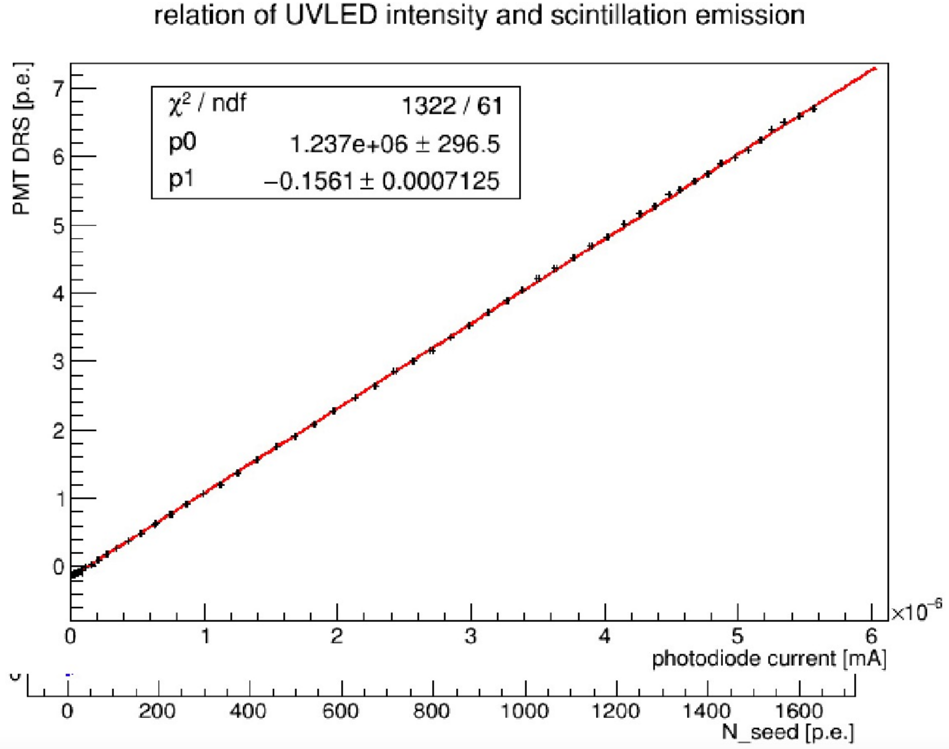
Saturation study Tokyo

New measurement setup

- SiPM saturation is studied by measuring SiPM current without using the attenuator
- Measuring relation between scintillation emission and UV-LED intensity by PMT to check the proportionality

New SiPM : 1600 pixels, 25 μm pitch
(Previous measurement : 4489 pixels, 15 μm
7296 pixels, 15 μm)
Scintillator size : 2 x 2 x 2 mm^3





Saturation study Tokyo

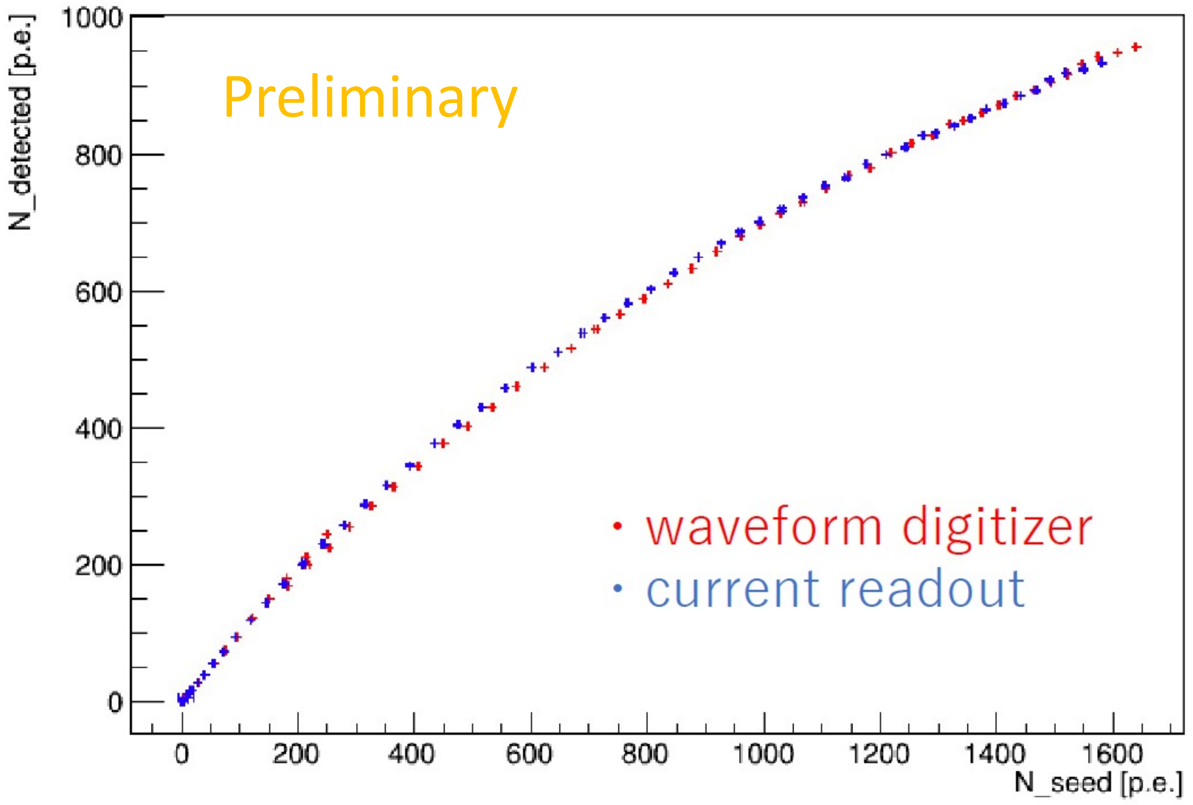
- Preliminary measurement was done with new setup

  ➡ Waveform digitizer : same as the previous measurement
  ➡ Current readout : new method

  ➡ There is no difference between readout type
  ➡ At this level, waveform distortion may not be problem

- Full measurement with new setup will be started soon

  ➡ Measurement using visible light pulse will also be done for comparison



No correction for after-pulsing

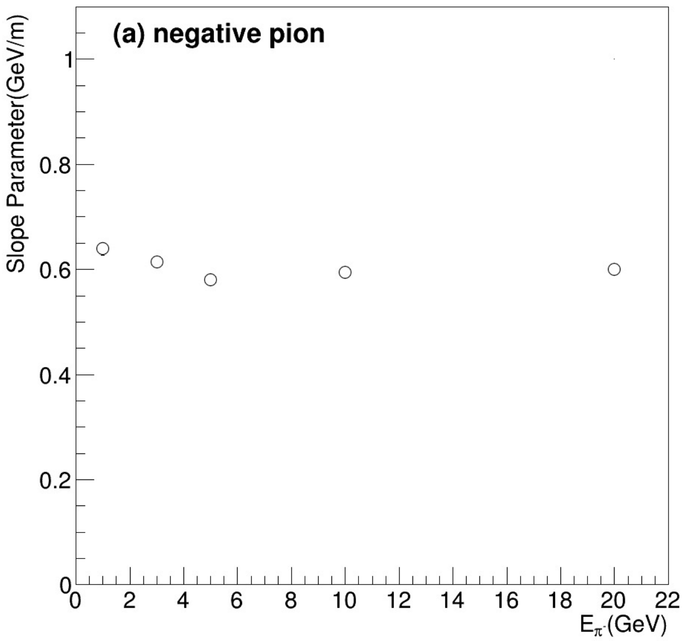
Dual readout with homogeneous material

Shinshu

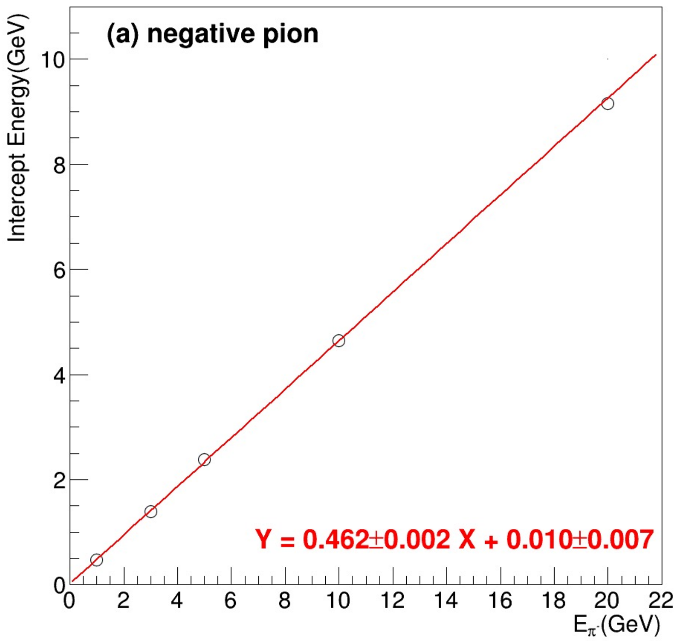
- A relation between track length(TL) and deposited energy(ED) in homogeneous calorimeter by GEANT4 simulation at high energy (arXiv:2010.07480 JINST)

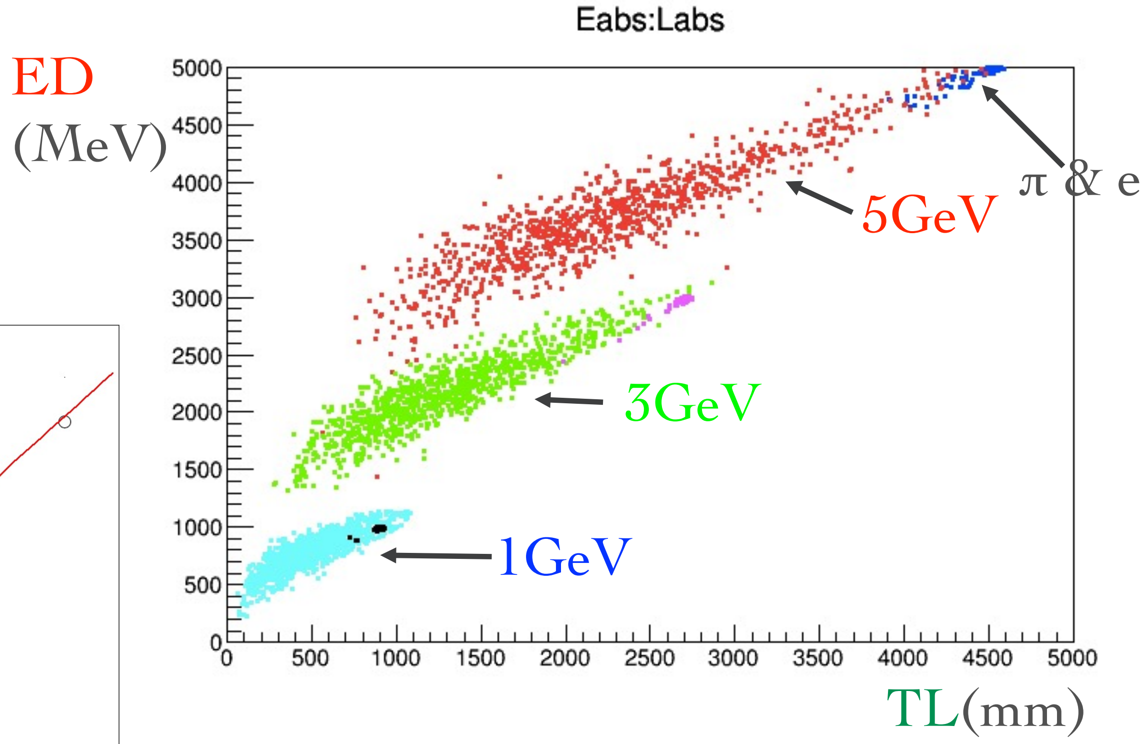
➡ Slopes are the same to incident energies
➡ Intercepts are linear to incident energies
➡ For both electron and pion

Slope



Intercept



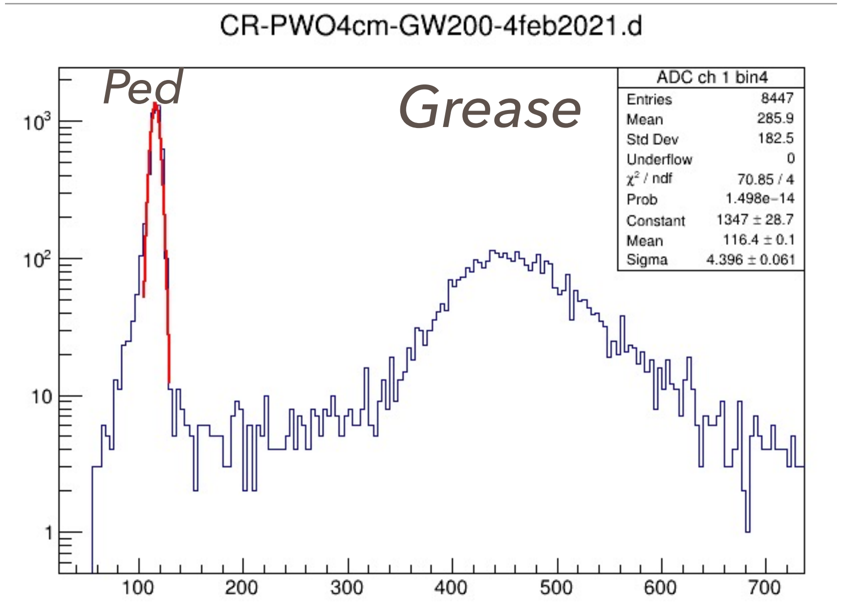


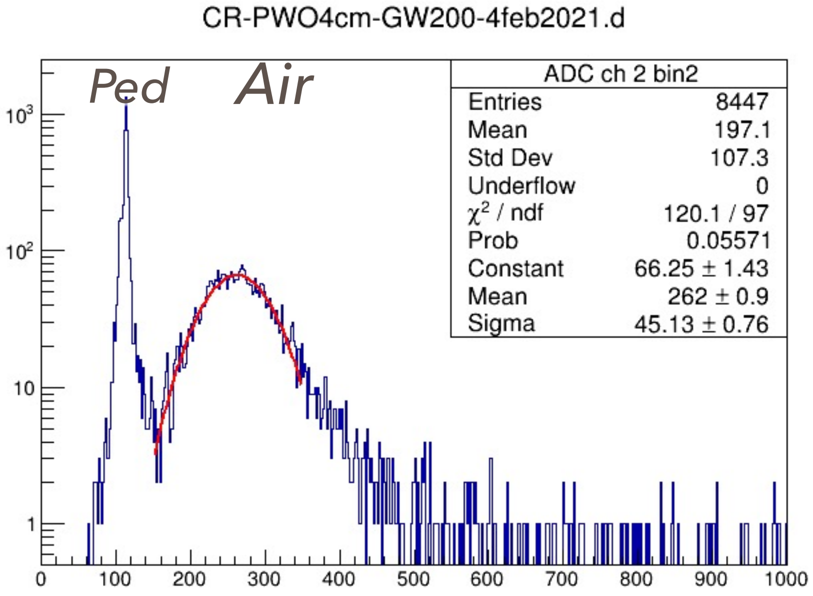
Dual readout with homogeneous material

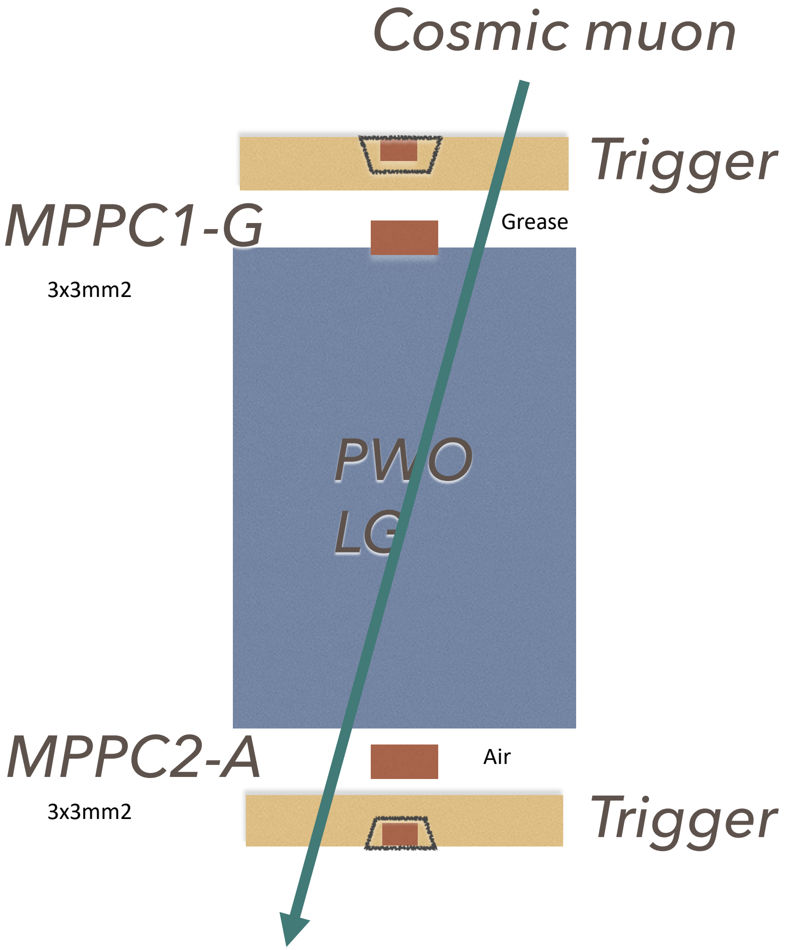
Shinshu

- With experiments from TL and ED to Cherenkov and Scintillation lights in a small PbWO4 (3 x 3 x 4 cm^3) block

- Separate by using refraction const.
  ➡ PD with grease and air couplings







Dual readout with homogeneous material

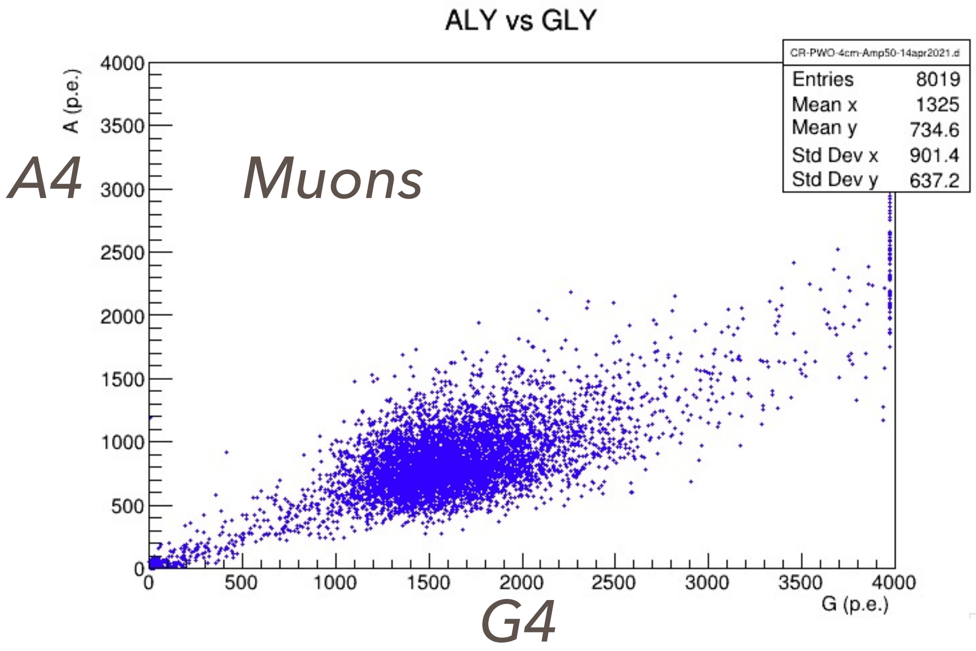
Shinshu

Tentative results

- With passing cosmic muons
  ➡ Grease and Air ~ length of PbWO4 (4 and 3 cm)
  ➡ Grease / Air ~ 3 / 1

Suppose Grease ~ Scintillation + Cherenkov and
Air ~ Scintillation only → 2 * (Scintillation) = (Cherenkov)

Different
from experience



PWO	Grease (p.e.)	Air (p.e.)
4cm	89	30
3cm	68	23

Summary and Prospects

- Sc-ECAL prototype
  ➡ Full layer prototype constructed
  ➡ Various calibrations in progress
  ➡ Performance is studied with cosmic-ray data
  ➡ To be tested in beam (DESY or IHEP)

- Strip study
  ➡ Optimization study of dimple shape with measurement and simulation is ongoing
  ➡ Test of scintillator production with injection molding is ongoing

- Sc-ECAL simulation study
  ➡ Gap modification processor was tested → should be updated
  ➡ New processor for reproduction of the hit position dependence of light yield, double SiPM readout effects, gap between strips is under development

- Saturation study
  ➡ New method to measure SiPM saturation using UV laser is under study
  ➡ Saturation measurement with improved setup is soon to begin

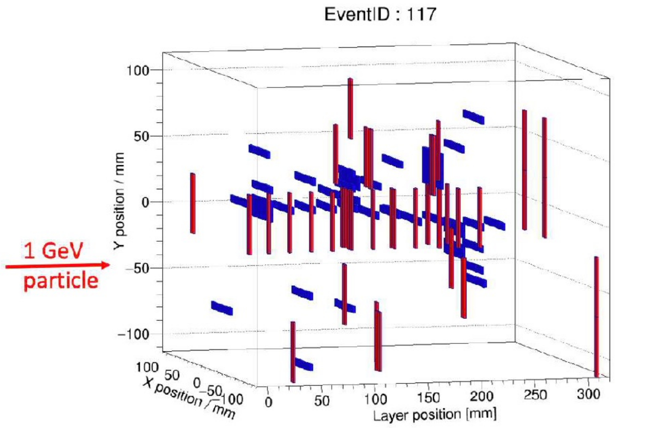
- Dual readout with homogeneous material
  ➡ Tentative simulation was done → p.e. of grease coupling is about three times of air coupling

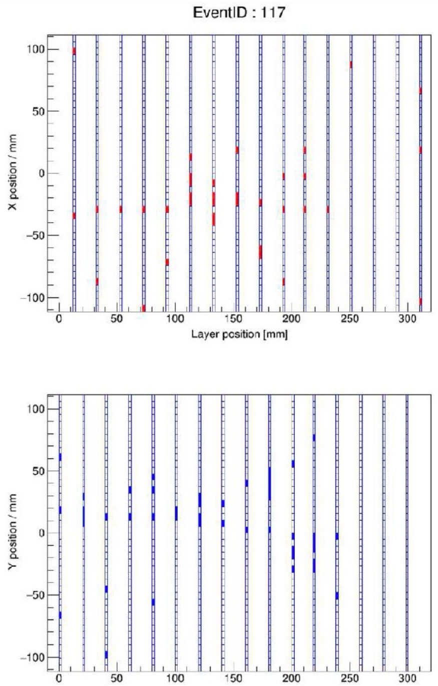
Backup

Beam test of Sc-ECAL prototype at IHEP

➡ Event building analysis was successfully done

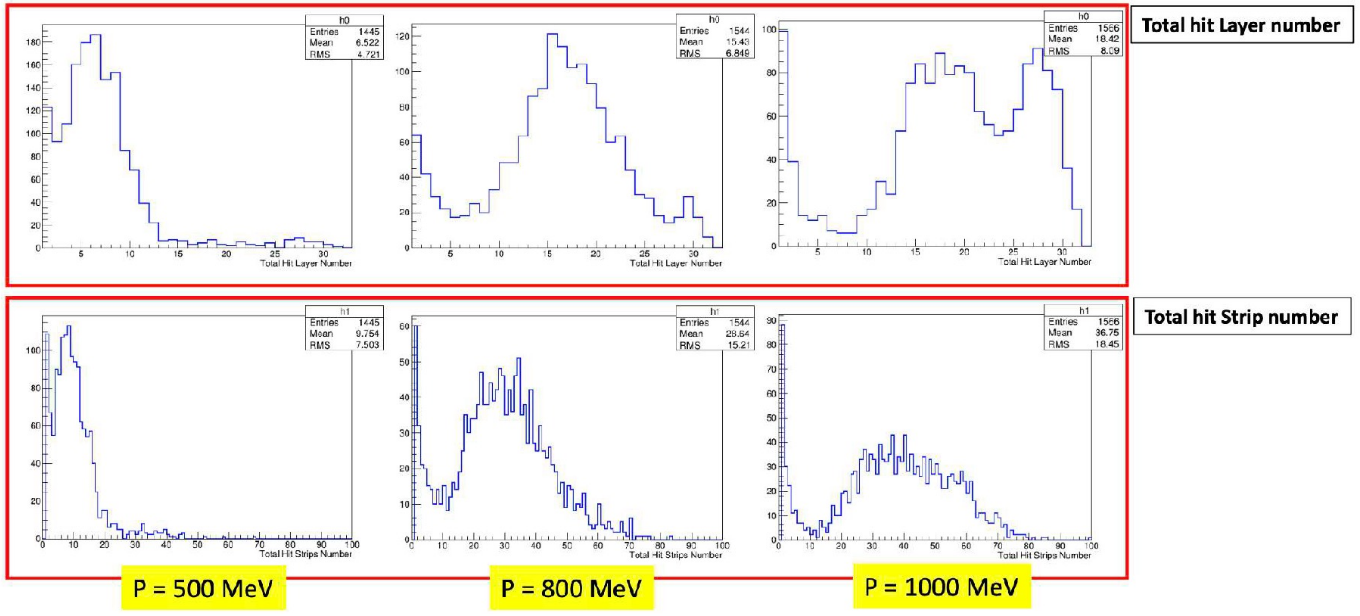
Proton candidate event





- Hit distribution is widely spread

➡ There is a room for beam collimation



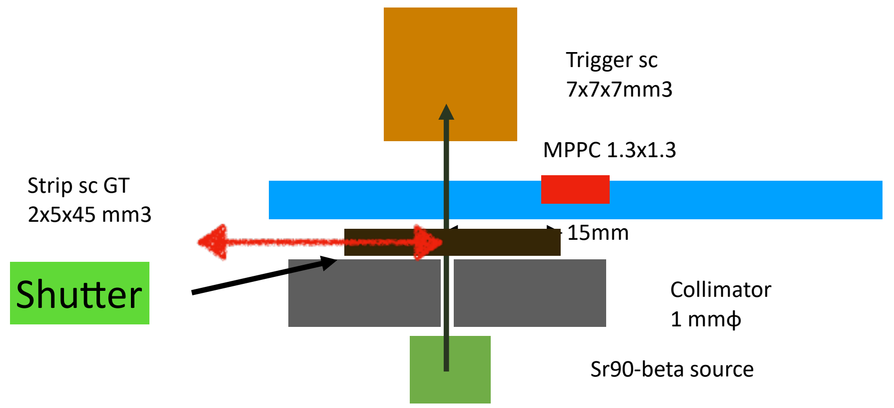
Backup

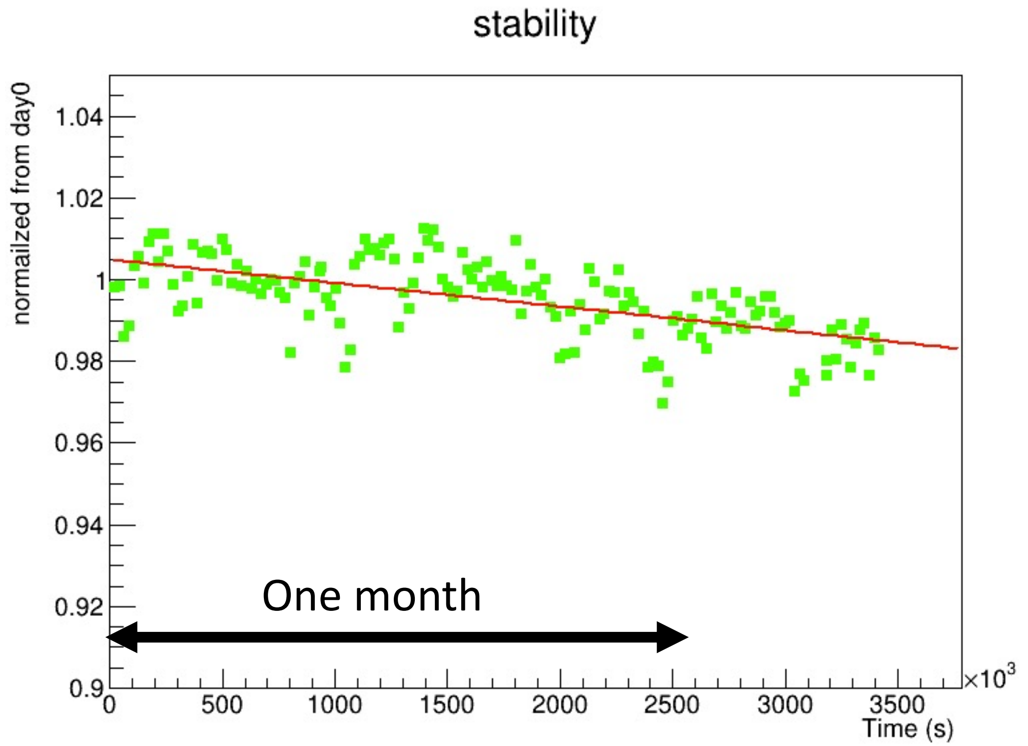
Strip long term stability

- With beta rays

  ➡ Gain change = - 0.005%/day ~ 1%/year
  Fairly stable

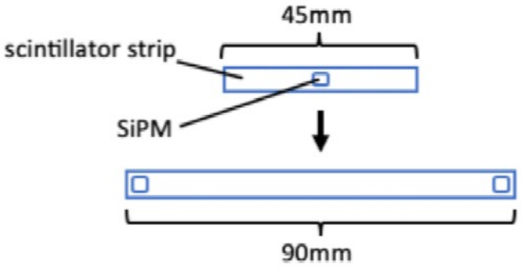
- While USTC reported - 0.05%/day gain decreased during cosmic runs for 3 months



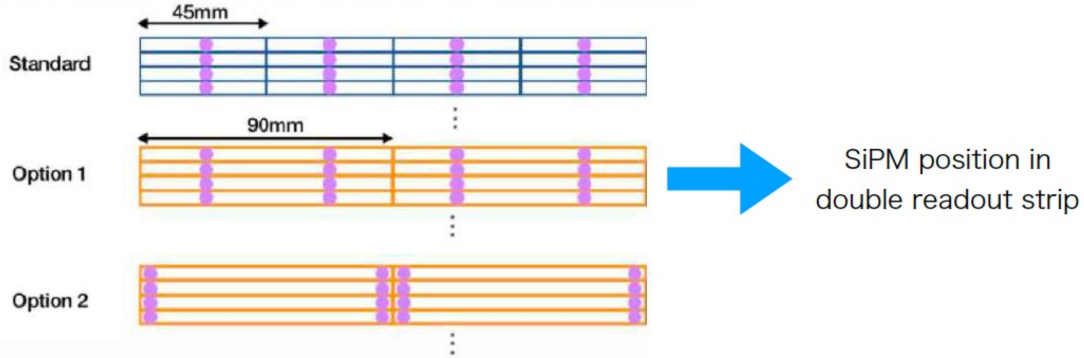


Backup

Double SiPM readout (See 15aSE-8)



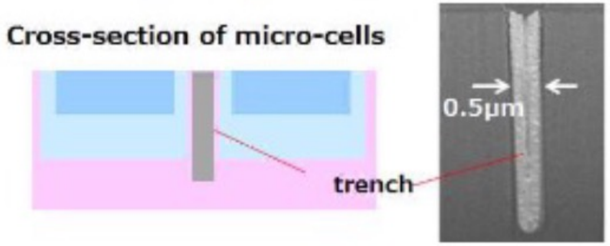
- **Readout by 2 SiPMs at strip ends**
- Twice longer strip (L=90mm) to keep the number of SiPMs
- Possible advantages
  - Eliminating noise by taking coincidence
  - Higher light yield by summing 2 SiPM readouts
  - Even lower light yield for each SiPMs (→less saturation)
  - Position reconstruction 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

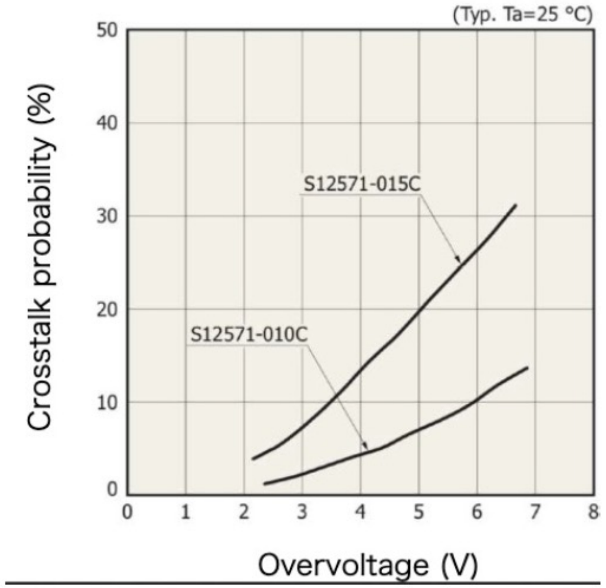


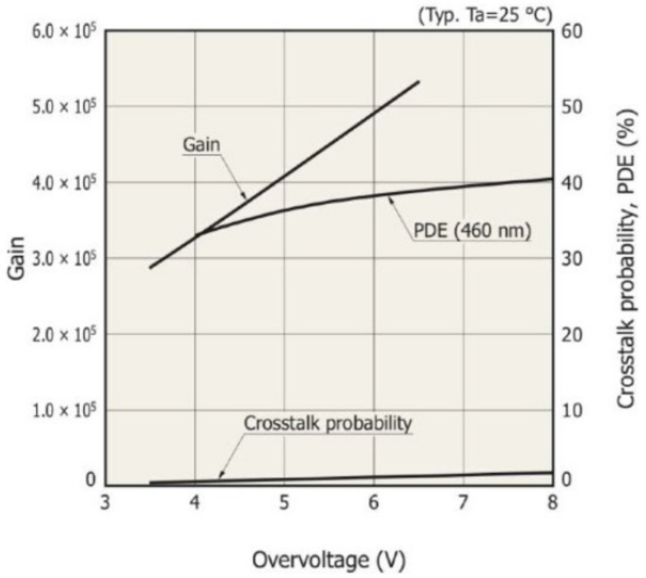
Backup

SiPM for Sc-ECAL

- Hamamatsu MPPC S12571-015P
  - Small pixel size : 15 μm
  - Active area : $1\times1 mm^2$
  - Breakdown voltage : 65 V
  - No trench isolation
- Hamamatsu MPPC S14160-1315PS
  - Small pixel size : 15 μm
  - Active area : $1.3\times1.3 mm^2$
  - Breakdown voltage : 38 V
  - 0.5 μm trench isolation







Crosstalk : carriers from avalanche in fired pixel firing adjacent pixels

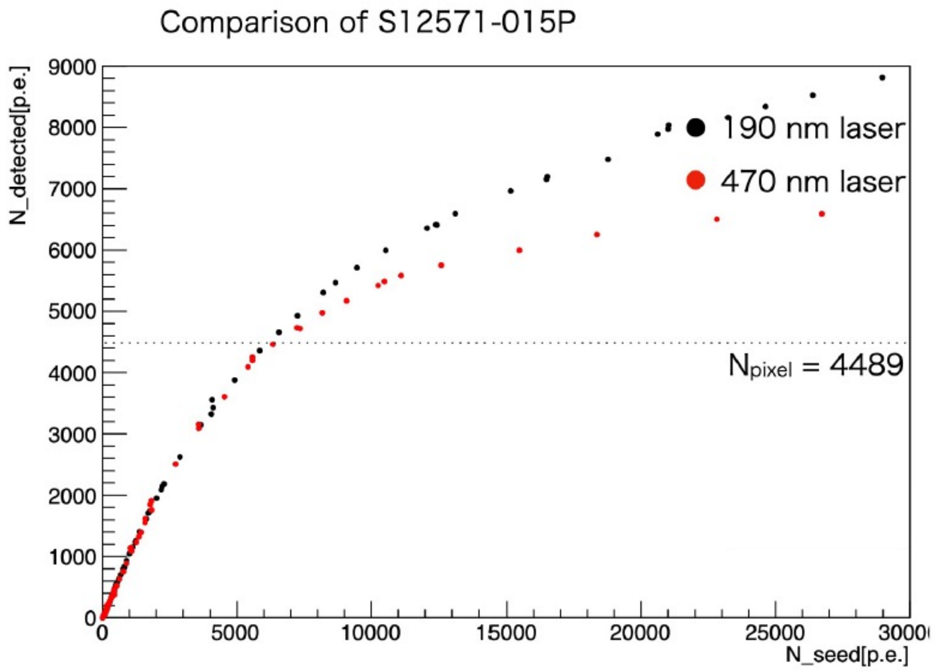
Trench : separation between pixels

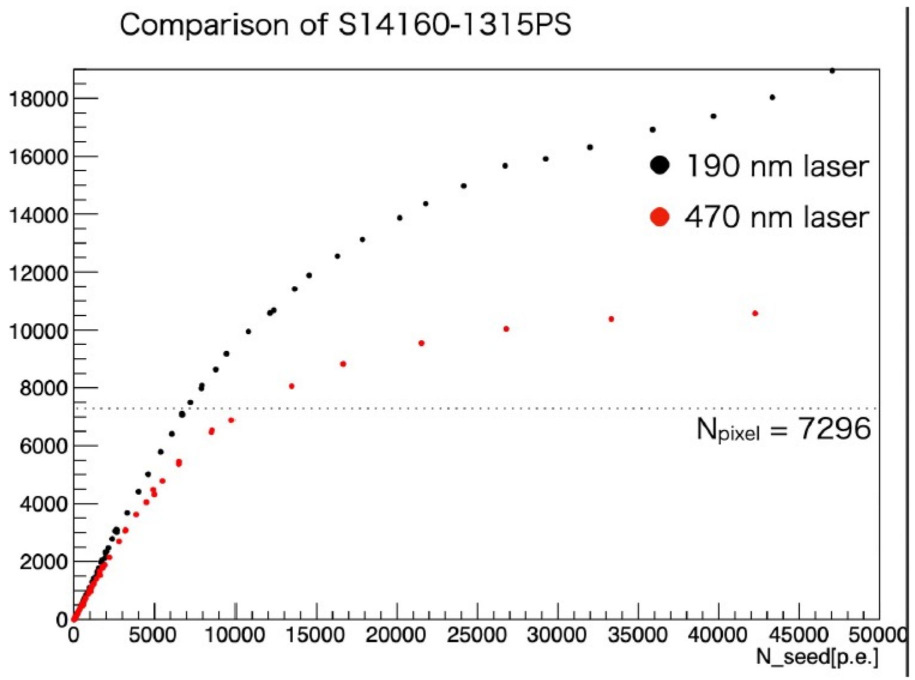
Hamamatsu Photonics K.K.
Opto-semiconductor Handbook

Backup

Result of previous measurement

- Saturation curve was measured for UV-laser and visible light.





Backup

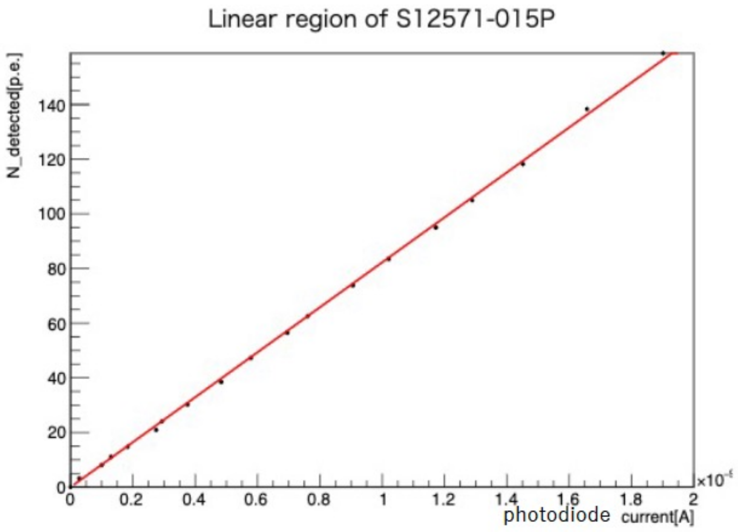
Possible issues

- The assumption in this measurement :

  scintillation emission is proportional to the intensity of the injected UV-laser in whole range

  - Used this relation in whole rage to estimate $\mathrm{N_{seed}}$
  - This proportionality must be experimentally confirmed.

- We measured the relation between scintillation emission and the intensity of the UV-laser over the whole range.

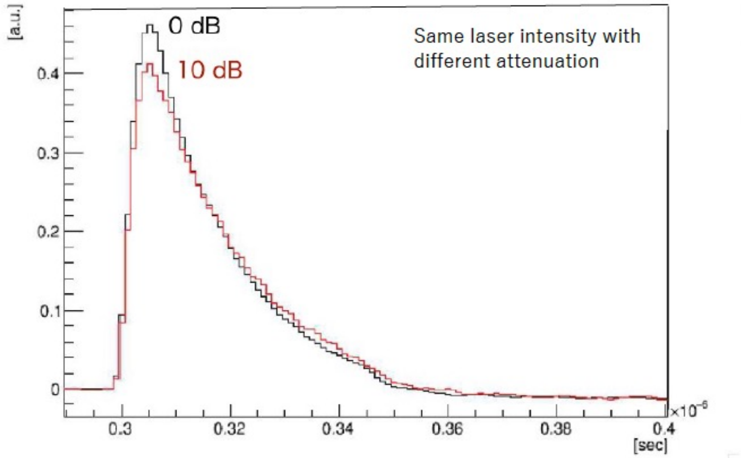


Backup

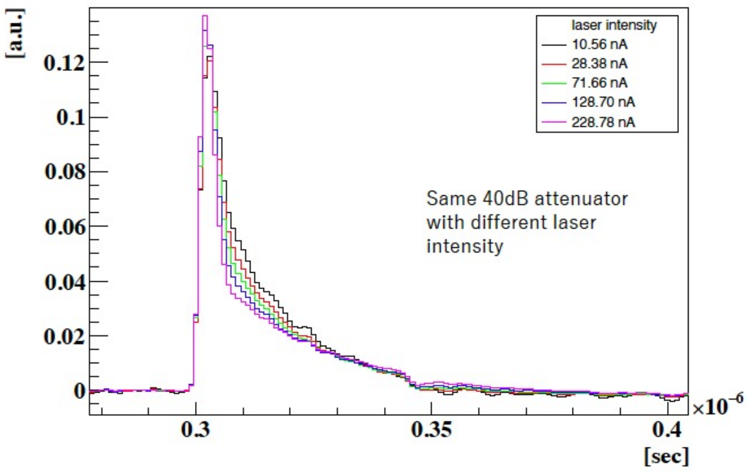
Possible issues

- Different signal attenuators are used depending on the signal light.
    - To avoid saturation of electronics, signal attenuator is inserted.
    - High frequency region is more attenuated than low region.
- Signal waveform will change as UV laser intensity increases.
    - This shape change affects estimation of photoelectrons.
- To avoid the effect of the limited bandwidth of the signal attenuator, SiPM saturation is studied by **measuring SiPM current** without using the attenuator.

Waveforms with 0dB/10dB



waveforms with 40dB attenuator



Backup

New measurement setup

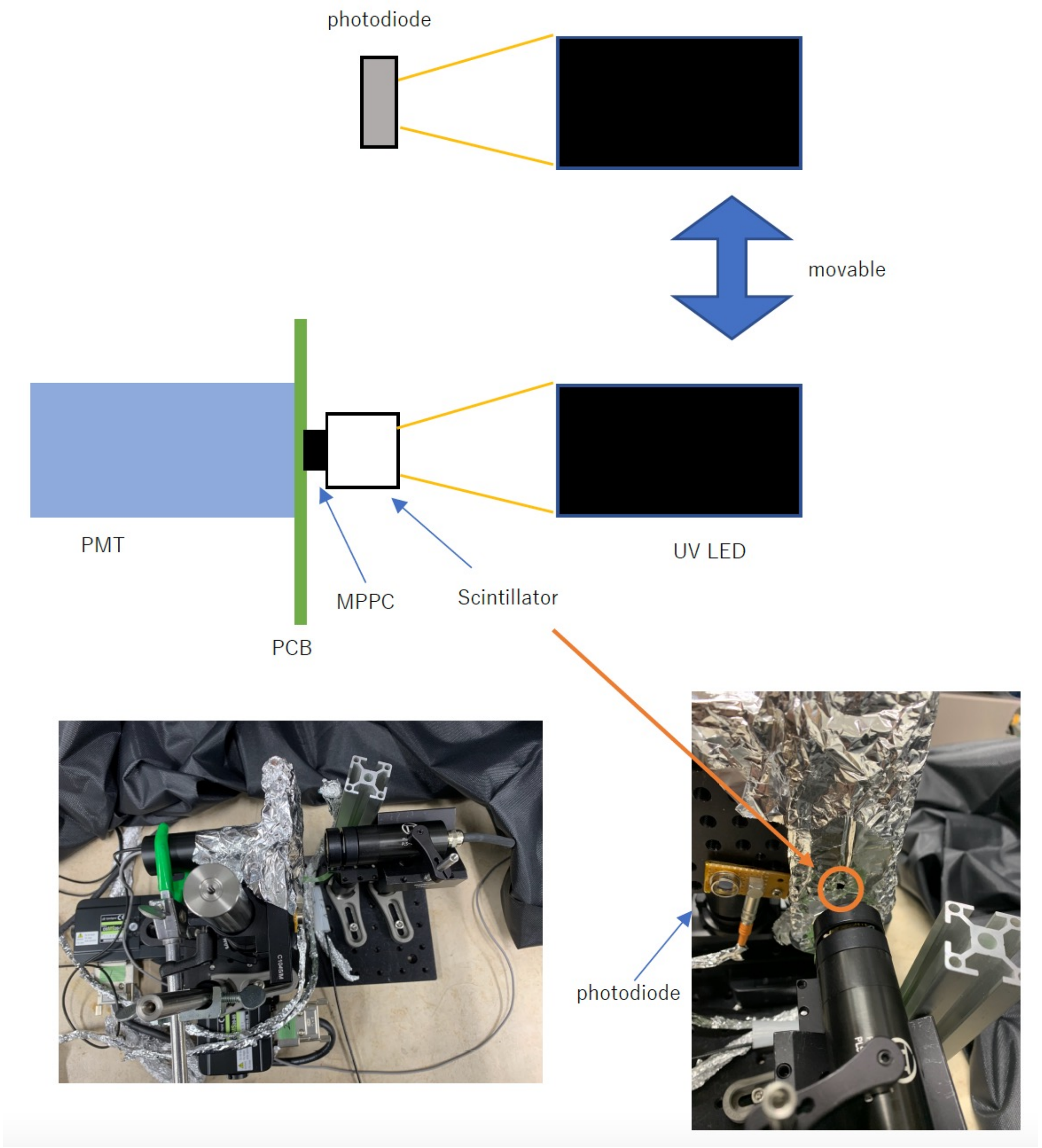
➡ Photodiode detects intensity of UV-LED

➡ PMT measures relation between scintillation emission and UVLED intensity

- PMT and MPPC are measured at the same time

- The whole set up is movable

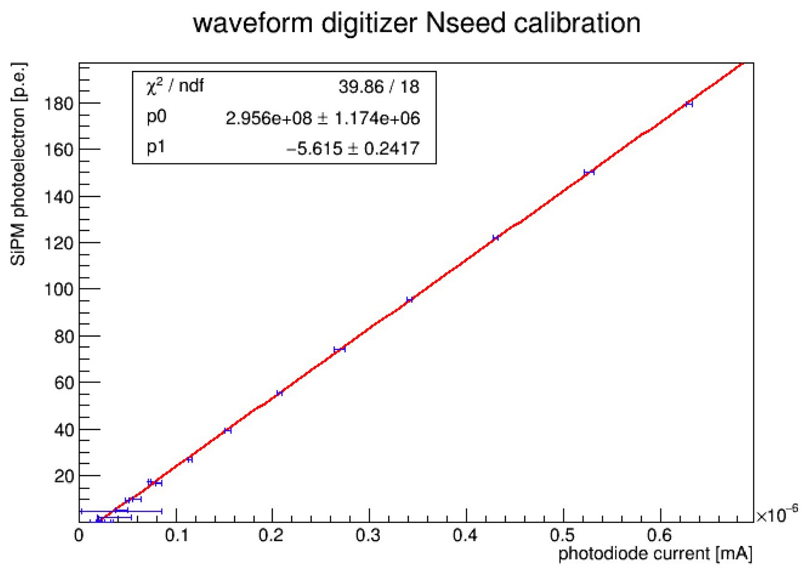
➡ UV-LED irradiate scintillator and photodiode



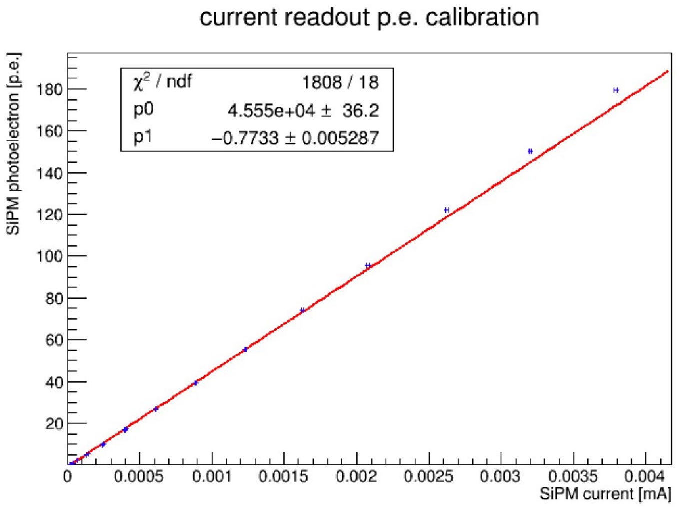
Backup

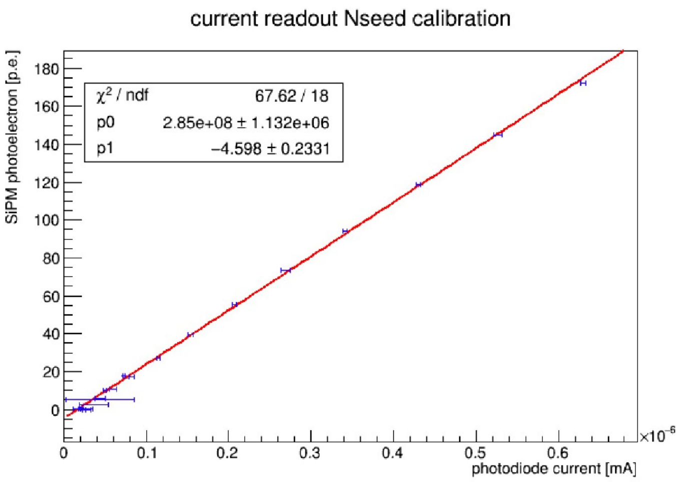
Analysis of saturation study

- Waveform digitizer data
  ➡ Data taken by waveform digitizer is analyzed in the same way as the previous measurement
  ➡ Estimated N_{seed} using relation between photodiode current and SiPM output at low laser intensity



- Current data
  ➡ Convert SiPM current [mA] into photoelectrons using relation at low LED intensity
  ➡ Estimated N_{seed} using relation between photodiode current and SiPM output at low LED intensity





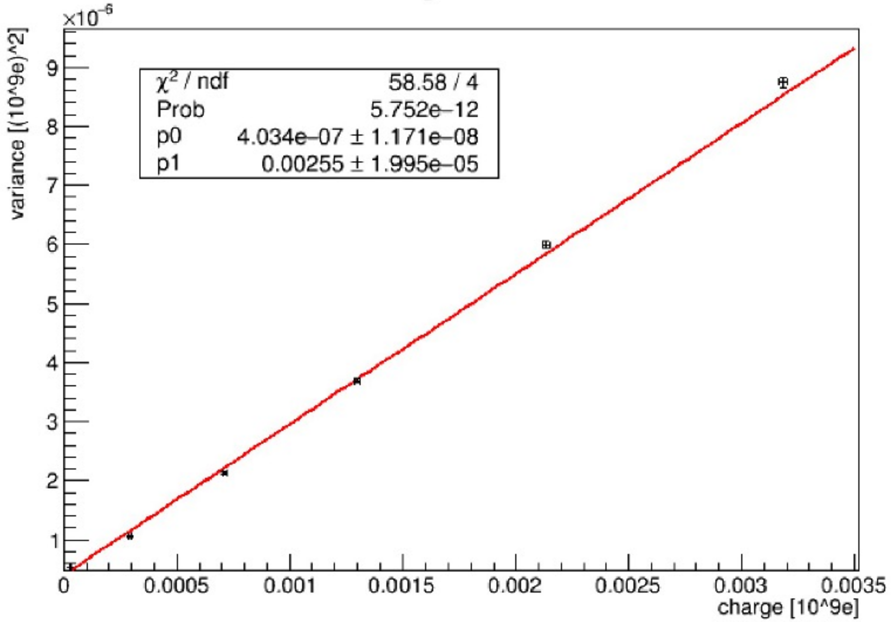
Backup

gain

PMT H6152-70

2.5×10^{6}

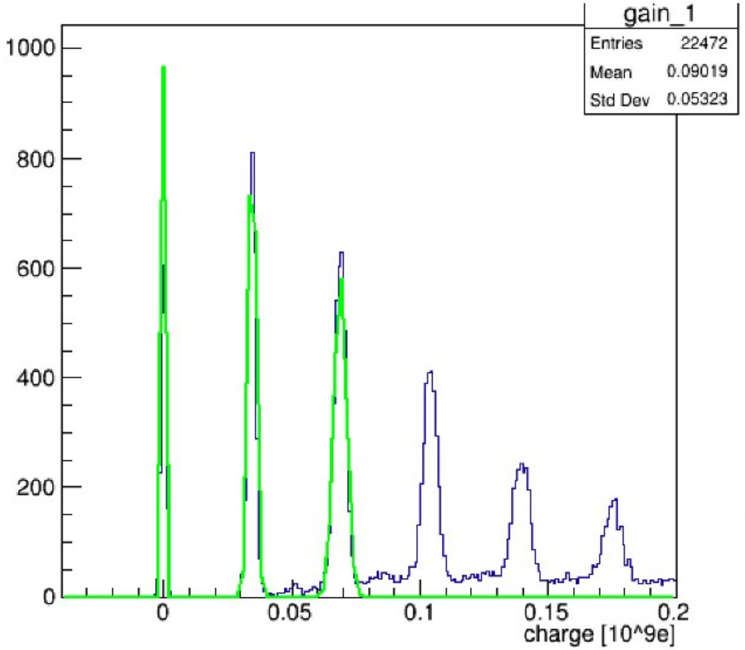
(catalog : 5×10^{5})

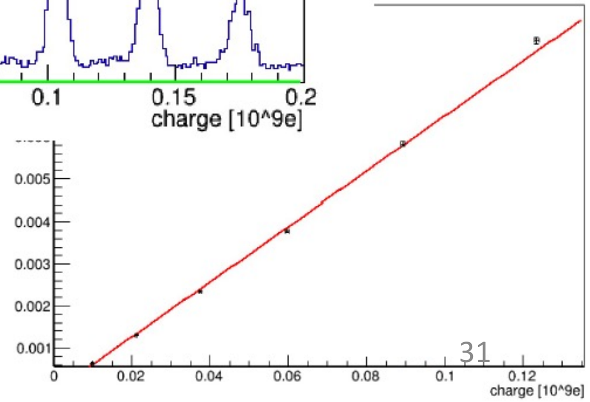


SiPM S12571-025P w/ amp

3.5×10^{7}

(catalog : 5.15×10^{5} w/o amp)





New MPPC waveform comparison

- w/ and w/o attenuator at the same intensity of UV LED