Development of Scintillator Electromagnetic Calorimeter for ILD

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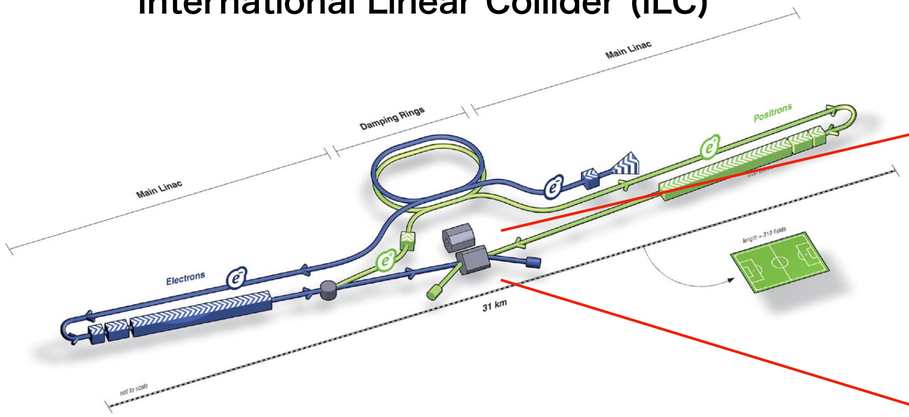
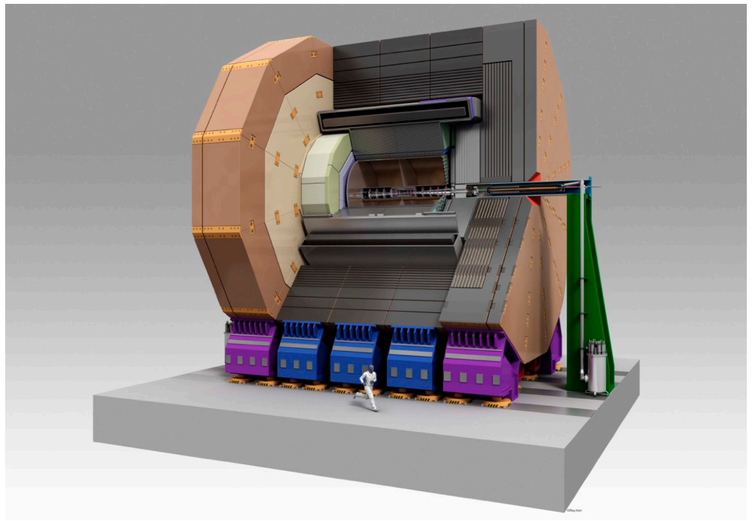
ILC project

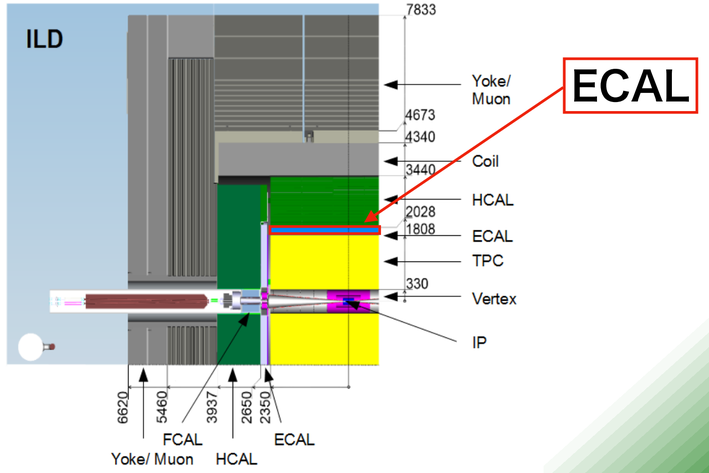
International Linear Collider (ILC)



International Large Detector(ILD)

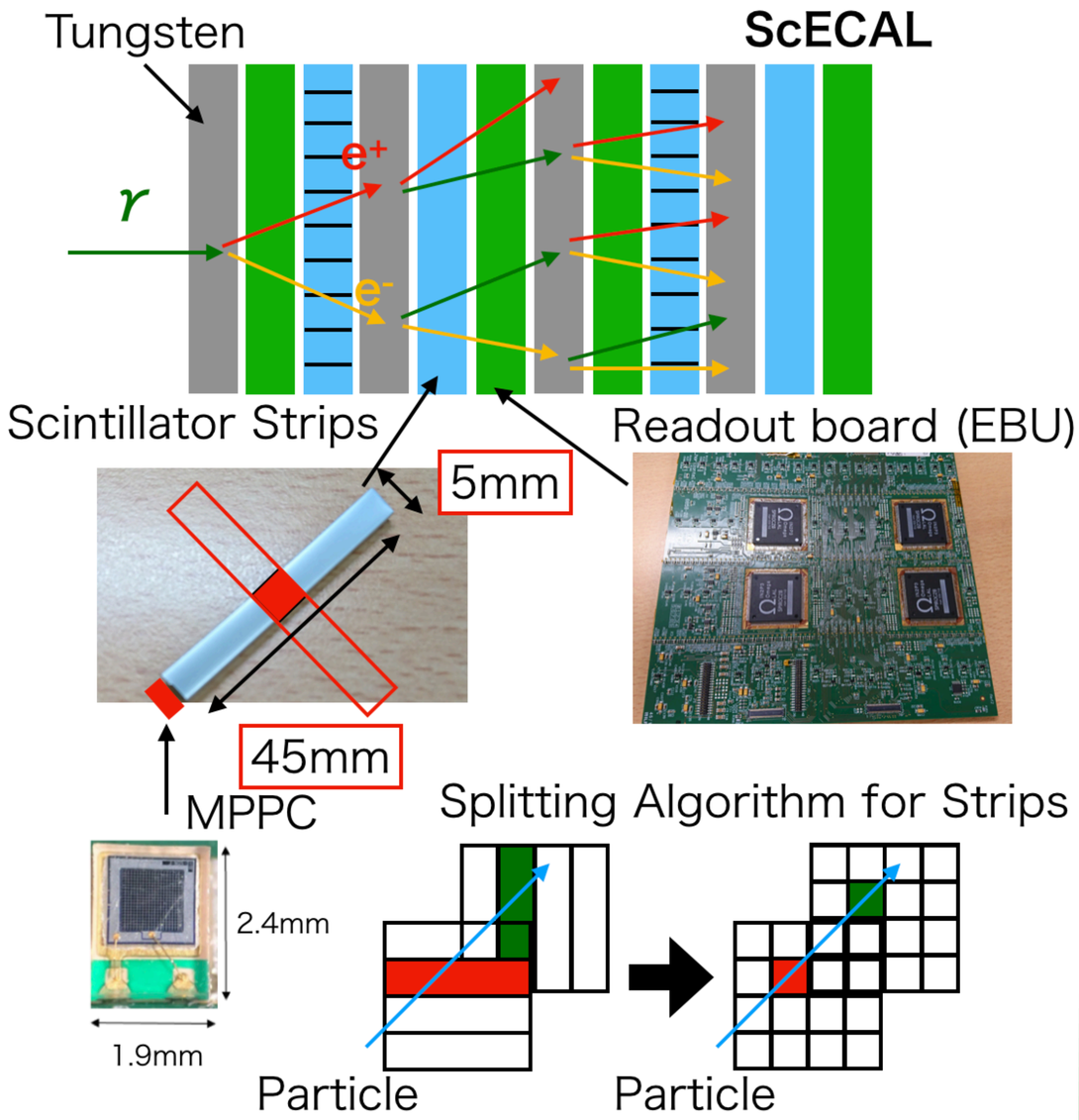


- International Linear Collider (ILC) is a project of a future electron-positron collider
- One of its goals is precise measurements of the Higgs particle
- International Large Detector (ILD) has been developed as one of concepts of detector for ILC
- We are developing Electromagnetic Calorimeter (ECAL) with SiPM as one of candidates of ILD ECAL
- ECAL mainly measures the energy of photon



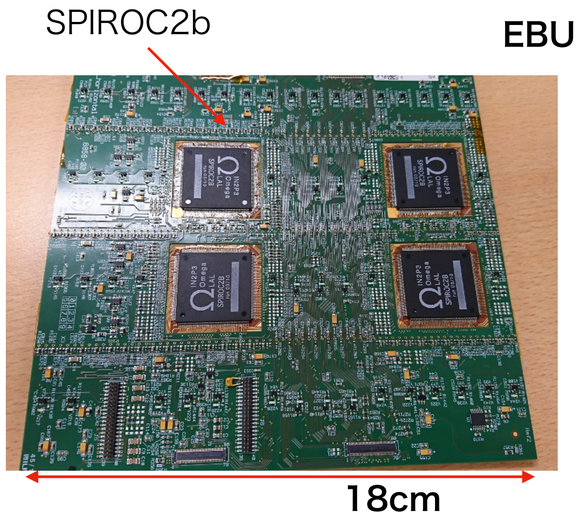
ScECAL

- We are developing Scintillator Electromagnetic Calorimeter (ScECAL) using tungsten, scintillator, and SiPM
- Detection layer consists of the scintillator strips (45mm x 5mm x 2mm) and strips in the neighboring two layers are aligned orthogonal each other
- The tungstens develop EM showers and scintillators measure them
- Could split each scintillator into 9 virtual cells along its longitudinal direction
  - We are able to achieve 5mm x 5mm resolution effectively to satisfy the requirement of PFA.
- Scintillator strips are read out by SiPMs
- Readout board (EBU) is integrated into the detector

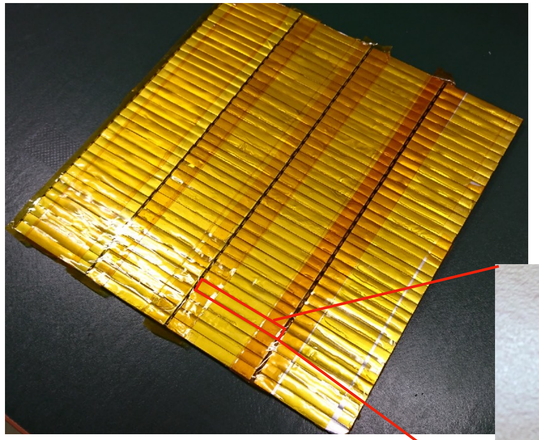


ECAL Base Unit (EBU)

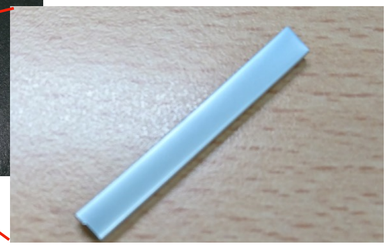
- EBU is an embedded readout electronics board for ScECAL developed by DESY
- 4 SPIROC2b chips developed by OMEGA are mounted on each EBU
- Each SPIROC2b chip amplifies and digitizes signals for 36 SiPMs
- Strips are mounted on the opposite surface to SPIROC2b
- LEDs are mounted for gain calibration of SiPMs



Top view



Bottom view



Scintillator layer

Development and motivation

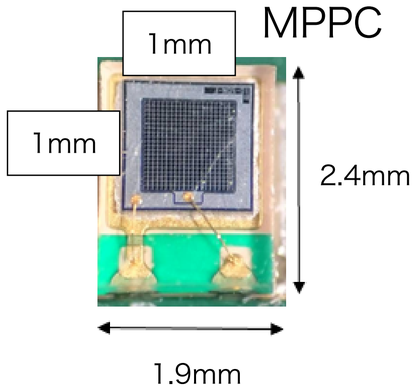
- We have to separate the lowest signal (1MIP) from noise with maintaining the dynamic range for ILD ECAL.
- We have attempted to use 10μm SiPM which has advantage of dynamic range.
- We have difficulties to fulfill the requirement with the EBU with 10μm SiPMs.
- We have tested a new prototype with 15μm pixel SiPMs
  - 15μm SiPM has larger PDE and gain than those of 10μm that we have been using

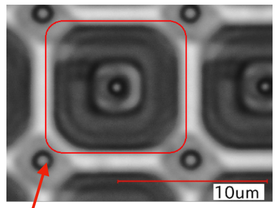
SiPMs

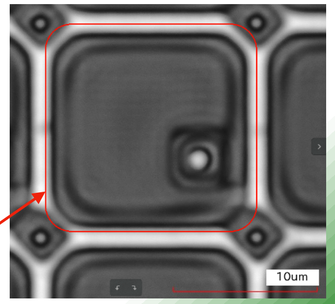
- We have been testing the 15μm and 10μm pixel SiPM
- In a comparison with the 10μm SiPM, we expect that the 15μm SiPM has
  - Doubled gain due to larger pitch size
  - 2.5 times larger PDE, as from geometrical fill factor

Hamamatsu catalog

Model Number	S12571-010P	S12571-015P
Photosensitive area	1mm^2	1mm^2
Pixel size	10μm	15μm
Number of pixels	10000	4489
PDE	10%	25%
Gain	1.35x10^5	2.3x10^5
Geometrical fill factor	33%	53%



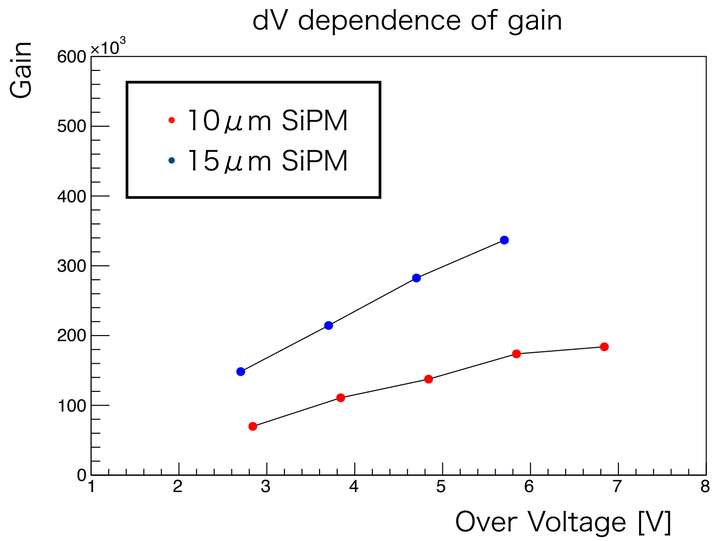


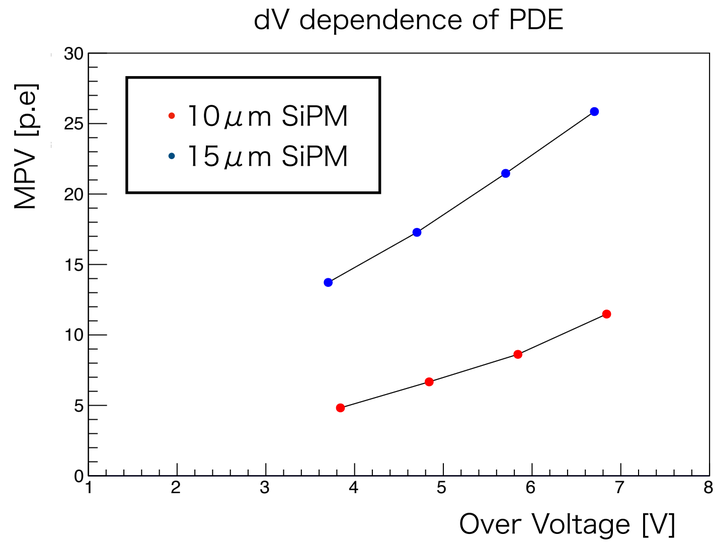


APD pixels of MPPCs

SiPM performance

- We measured the performance of 15μm pixel SiPM
- We compared 15μm pixel SiPM with 10μm pixel SiPM in terms of gain and PDE
- We compared SiPMs attached with 2mm thickness SCSN38 scintillator by CAMAC readout
- We confirmed that the15μm pixel SiPM has more than twice as large gain and PDE as those10μm pixel SiPM has

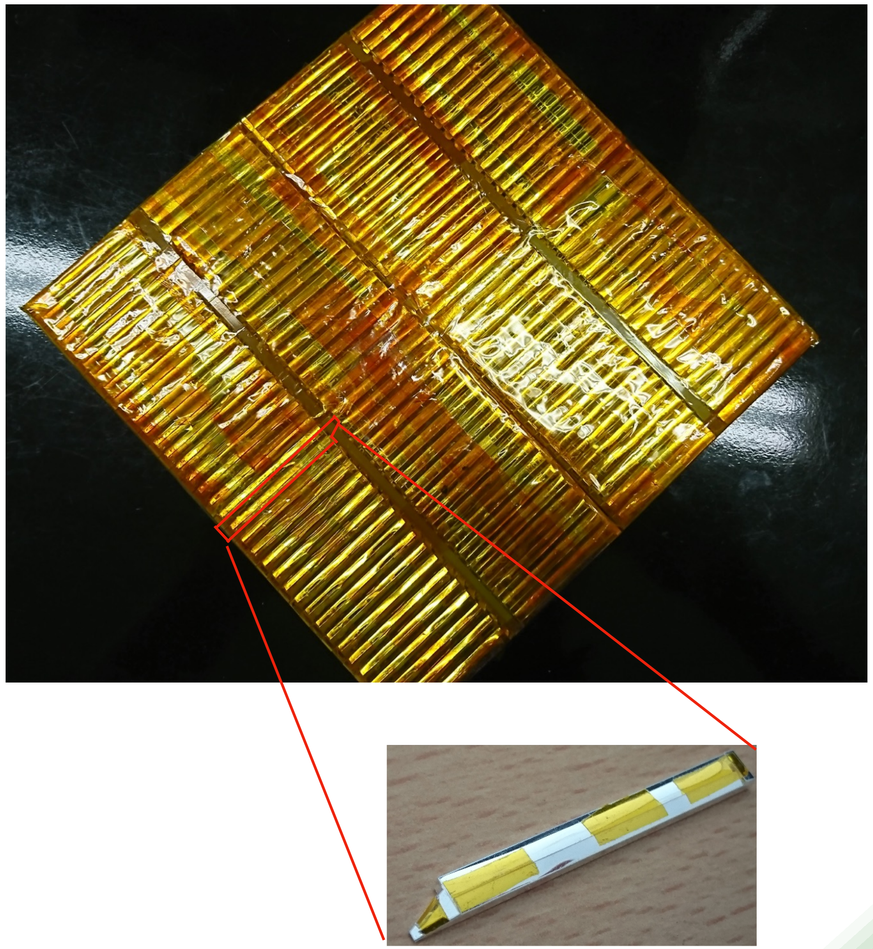




ScECAL prototype

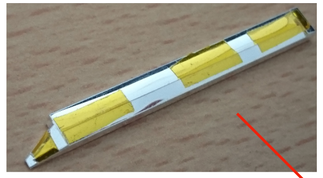
- 144 SiPMs and scintillator strips are mounted on an EBU
- 15 μm pixel SiPM
- Wedged shape strip
- Bottom readout design

ScECAL prototype

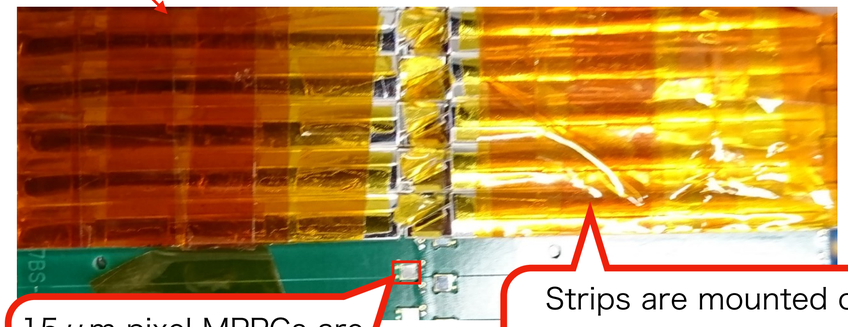


Bottom readout with wedged shape strip

- Scintillator strip is made of EJ204 manufactured by ELJEN
- In order to increase light collection efficiency, the tip of strip is shaped like a wedge
- Readout from bottom side in order to get rid of dead volume due to SiPM



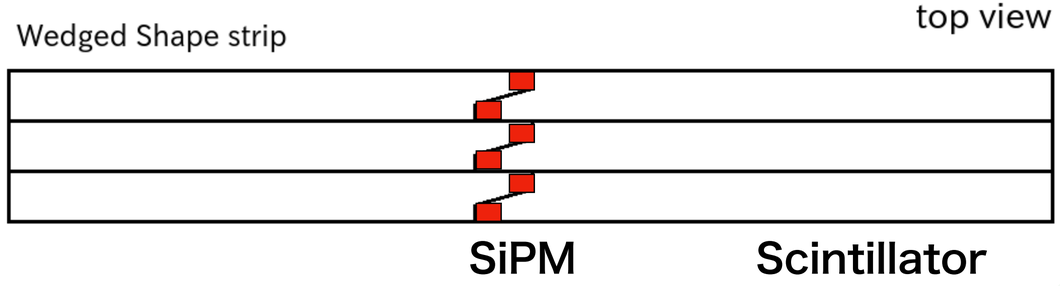
Wedged shape strips on intermediate board



15μm pixel MPPCs are mounted on EBU via intermediate board

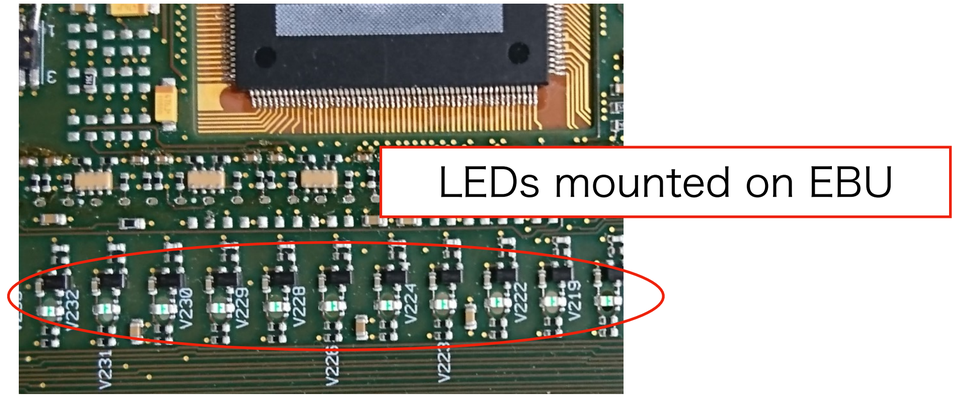
Strips are mounted on intermediate board

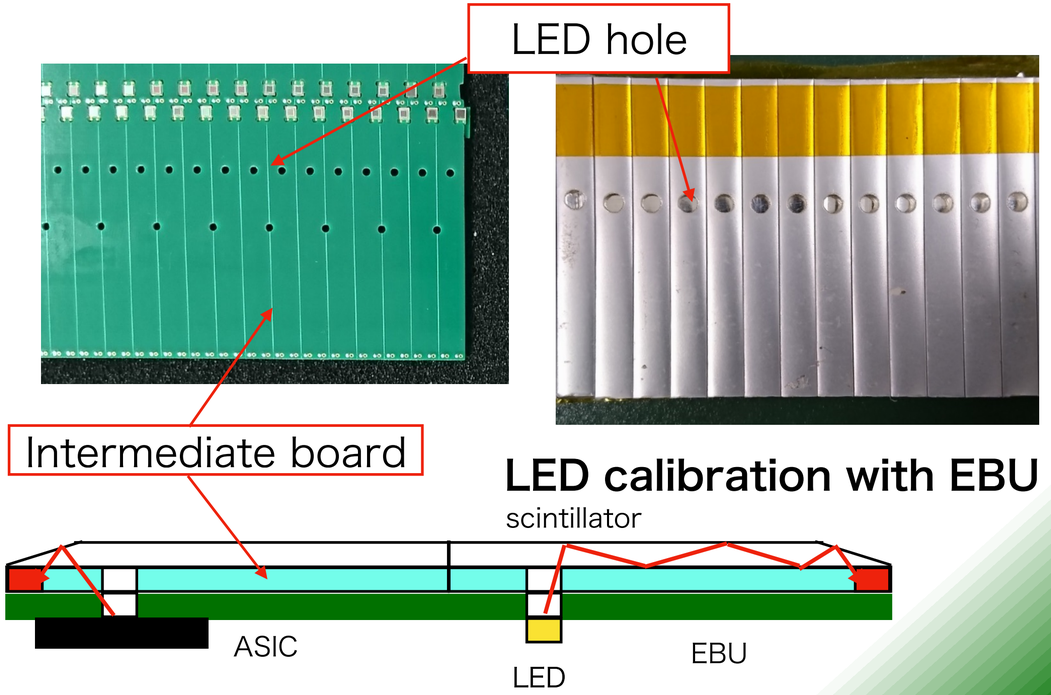
Bottom readout design



LED calibration test with EBU

- We attempted LED calibration with LEDs mounted on EBU
  - For gain monitoring
- We measured changing SiPMs input voltage by ~1V
- SiPMs are irradiated by LED light going through the hole of reflector and intermediate board that we use for mounting SiPM
- LED is not mounted in 36 channels out of 144
  - ASIC or connector is mounted on these channels
- We are able to detect LED lights from these channels with LED lights leakages from nearby channels

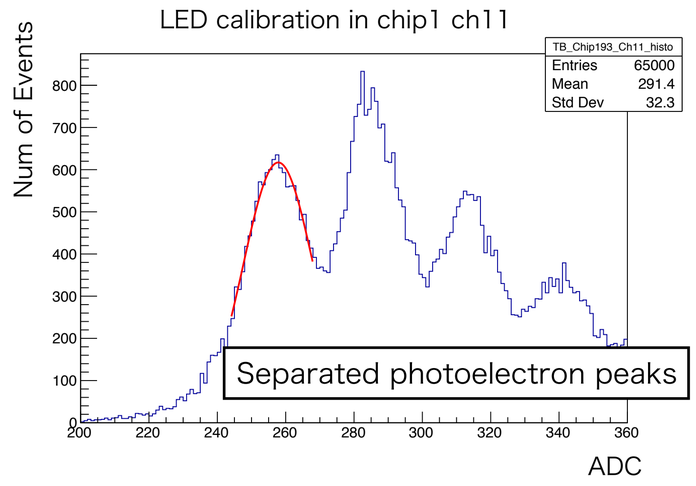


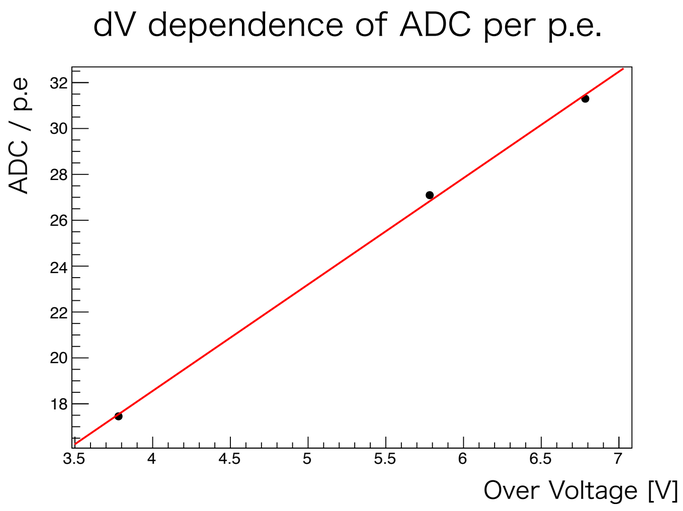


LED calibration with EBU

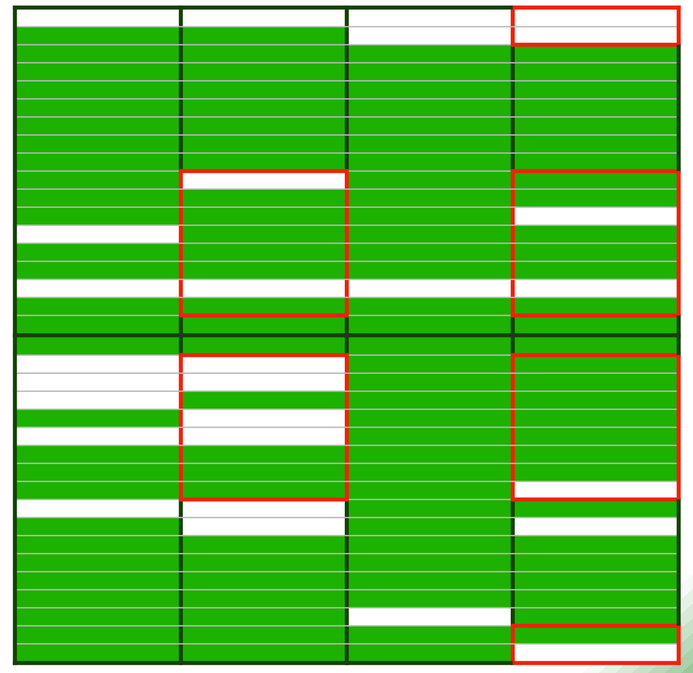
LED calibration test with EBU

- We checked linearity between gain and over voltage
- We obtained good linearity by LED test
- p.e. peaks are separated in 116 / 144 channels
- We detected p.e. peaks in 24 / 36 channels In which LED is not mounted
- We will tune SiPM and LED voltage more precisely for the channels in which p.e. peaks were not seen





Result map of LED calibration test

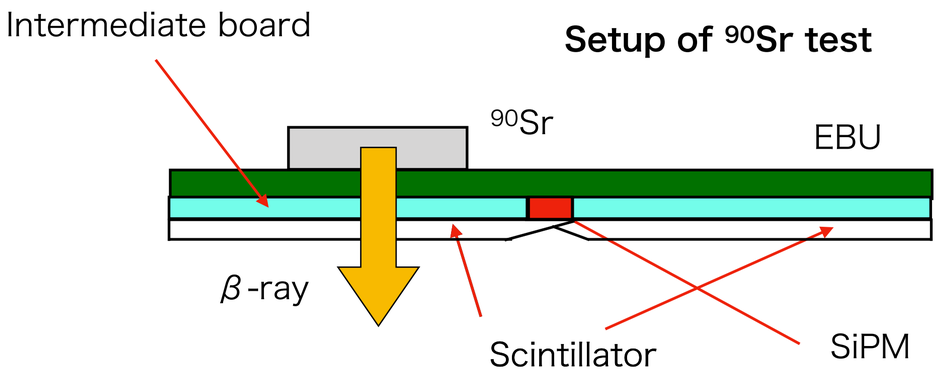


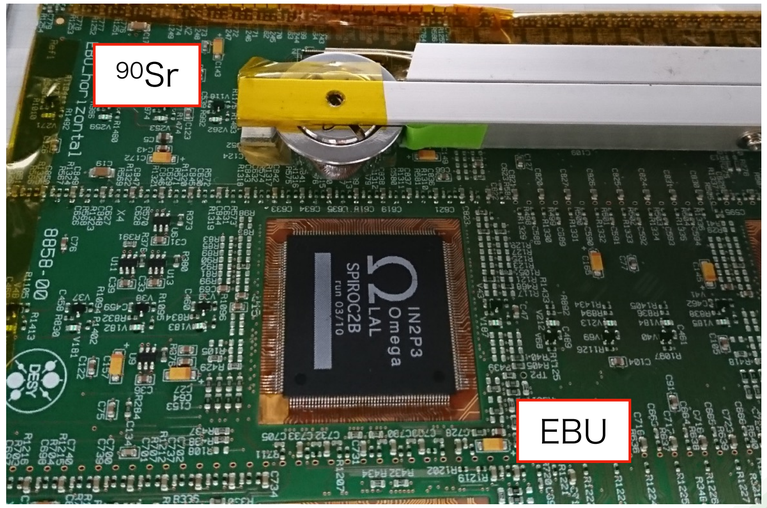
Photoelectron peak was separated

LED is not mounted

EBU test with ^{90}Sr

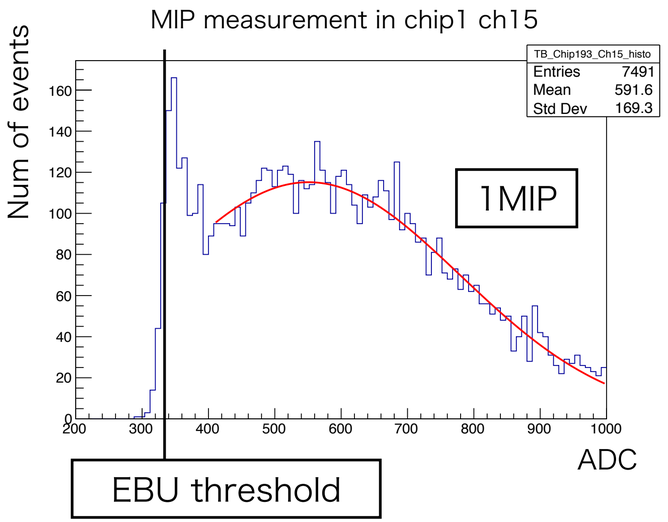
- We measured light yield of 1MIP channel by channel
- We measured light yield with beta rays passing EBU, intermediate board, and scintillator strip
- We tested all channels one by one with self trigger
  - We set threshold for each channel

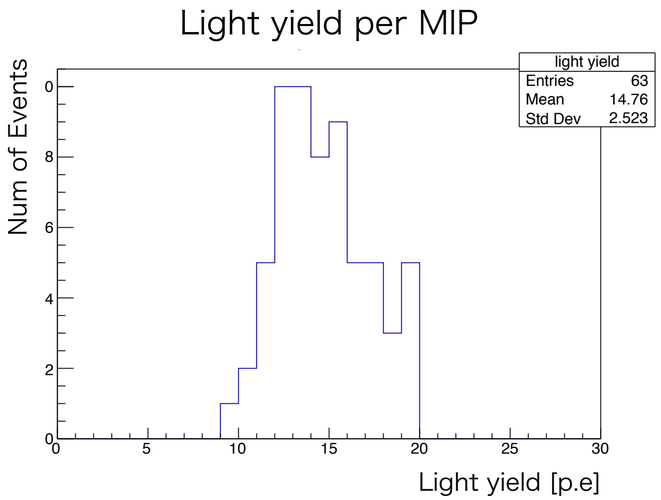




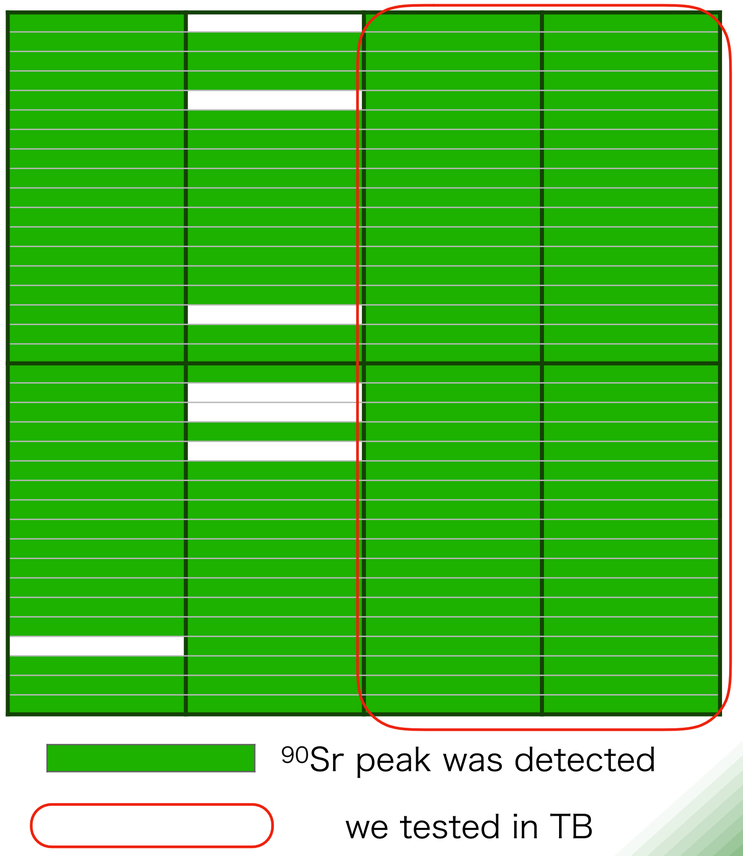
EBU test with ^{90}Sr

- We detected 1MIP peak separated from noise in 137 / 144 channels
- Average light yield per MIP was 14.8p.e.
- Tails of MIP peak was seen in other channels
- We could not detected MIP peak in these channel by last TB
- In last test beam, we tested 72channels





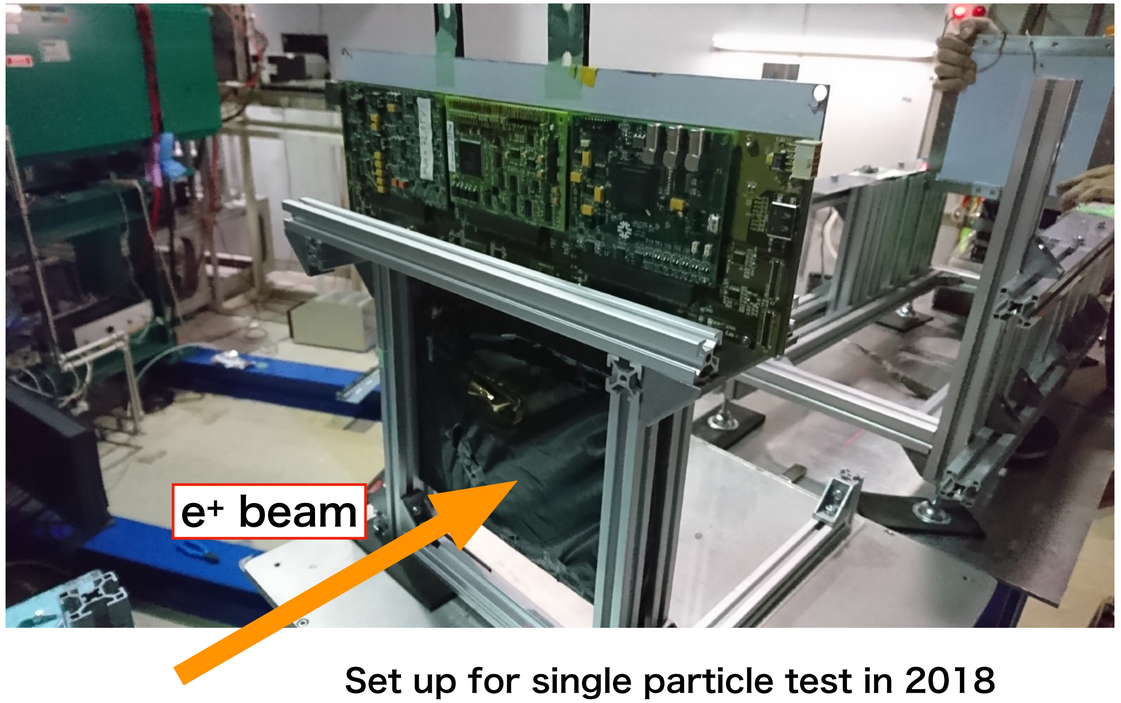
Result map of ^{90}Sr test



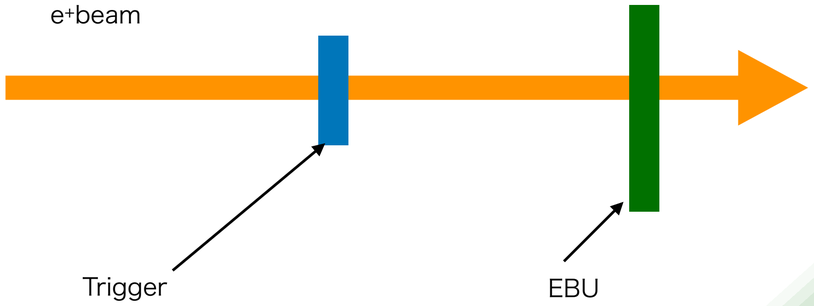
Test Beam @ ELPH

- In Nov. 22 to 25 @ ELPH (Tohoku Univ.)
- With 50 to 800 MeV positron beam
- We tested with active absorber calorimeter
  - Will be reported by Terada

EBU with flame in beam line



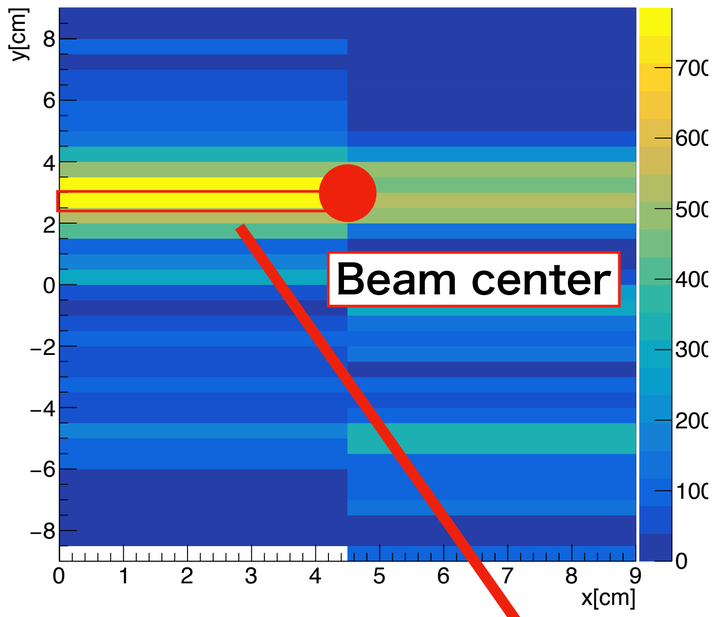
Set up for single particle test in 2018



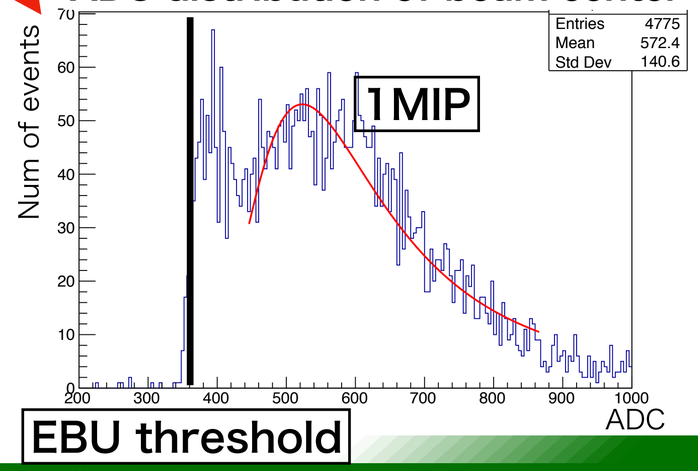
single particle test

- In this test, e^+ beam was injected to EBU directly
- We made hit map roughly with only EBU threshold as first step
- Hit was concentrated around beam center
- We obtained reasonable hit map
- MIP peak was seen in the channel of beam center
- We will make hit map with more precise cut such as MIP cut in order to remove the influence of noise

Hit map of single particle test

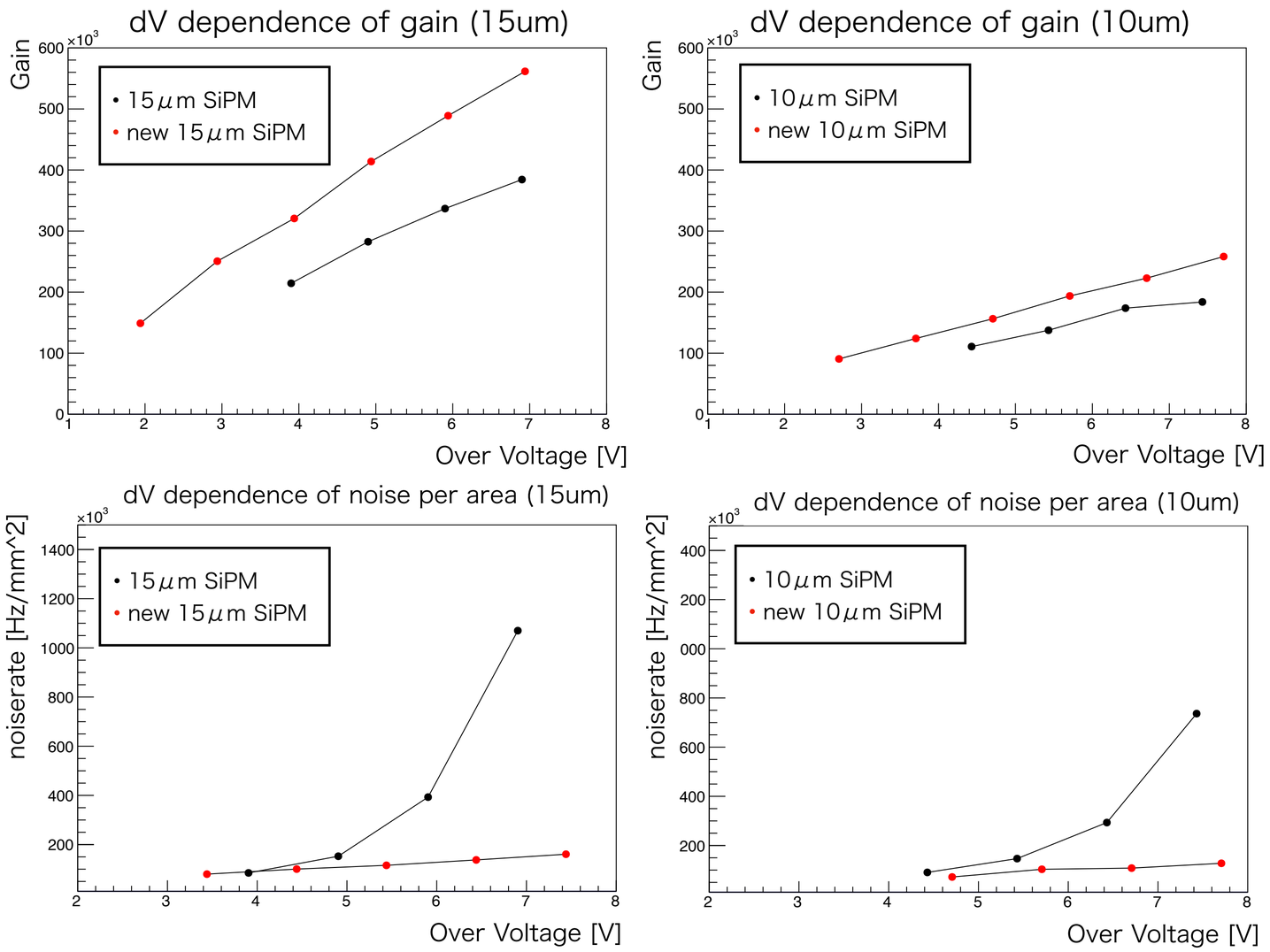


ADC distribution of beam center



Performance of new SiPM prototype

- We have tested new prototypes of SiPM with 10μm and 15μm pitch pixel
- Photosensitive area is 1.3 x 1.3 mm^2
- Trenches are formed between APD pixels in order to reduce optical crosstalk
- We can operate with lower voltage (~40V) than current SiPM
- Comparing with current SiPMs that have the same pitch size, new SiPMs have
  - 40% larger gain in 15μm SiPM
  - 30% larger gain in 10μm SiPM
  - Much lower noise rate
- We will measure optical crosstalk and test MIP measurement with EBU



Measured with CAMAC readout

Summary

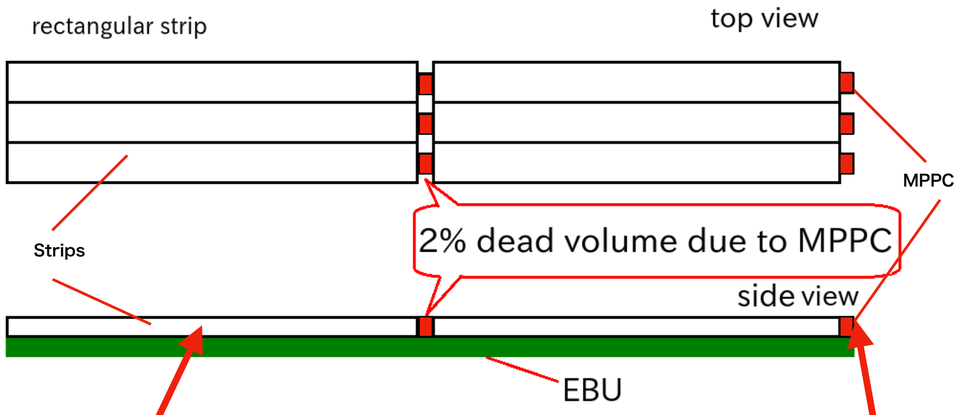
- We are developing ECAL with SiPM and scintillator for ILC
- We are planning to use 15μm SiPM for ILD ScECAL with current EBU/SPIROC2b in order to obtain enough gain and light yield for separation 1MIP from noise.
- We could detect separated p.e. peaks with LEDs mounted on EBU for gain monitoring.
- We obtained ~15p.e. per MIP in the test with ^{90}Sr.
- We tested EBU with 50 to 800 MeV positron beam at Tohoku University.
- We obtained reasonable hit map with rough analysis.
- We expect new prototypes of SiPM to improve S/N ratio, and we will test with EBU using LED and beta-ray source.

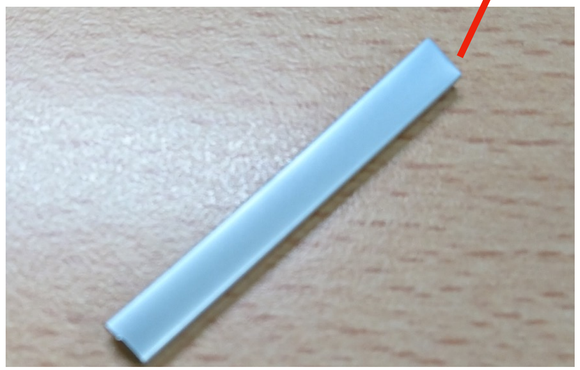
Backup

Preparation of Side readout layer

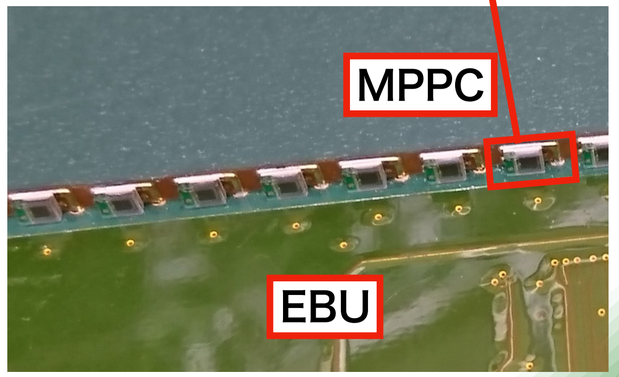
- We are preparing another EBU layer for next TB
  - Side read out design with 15 μm MPPC
  - Scintillator strips are made of EJ204
- We ordered Flex board for mounting MPPC on EBU

Side readout design





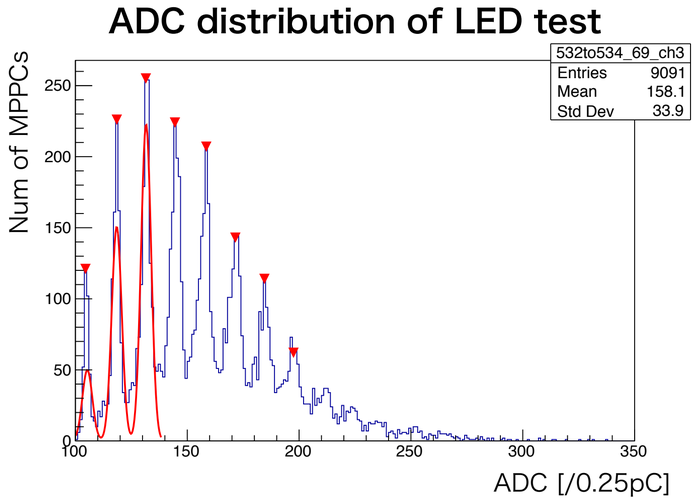
Rectangular strip

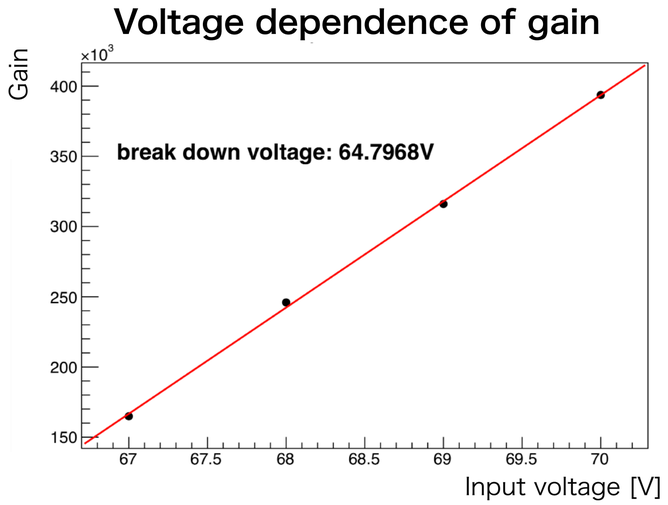


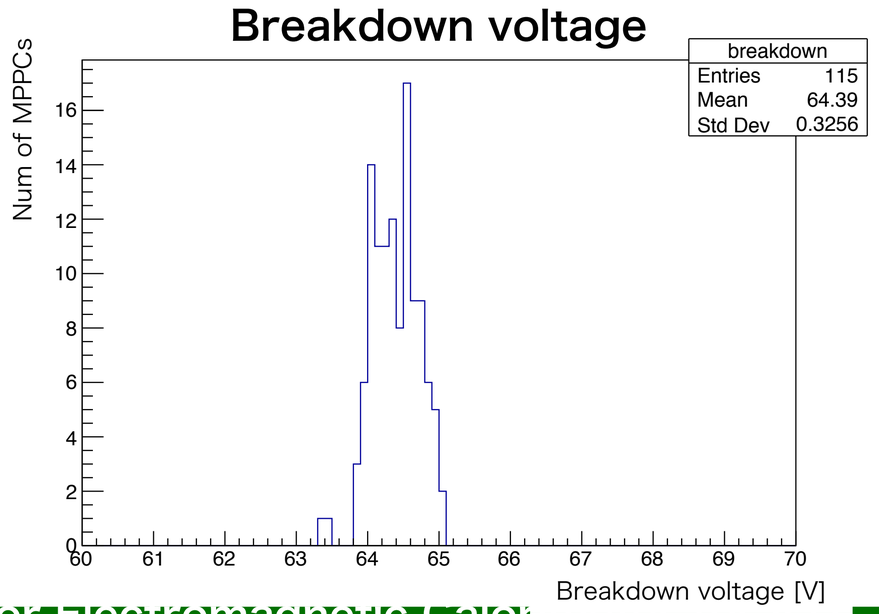
MPPCs on side readout EBU

MPPC test for Side readout layer

- We tested MPPCs with LED for side readout layer
- We measured individual difference of MPPCs in clearer condition before mounting on EBU
  - With CAMAC readout
- RMS of breakdown voltage for 115 MPPCs is 0.3256
  - small individual differences

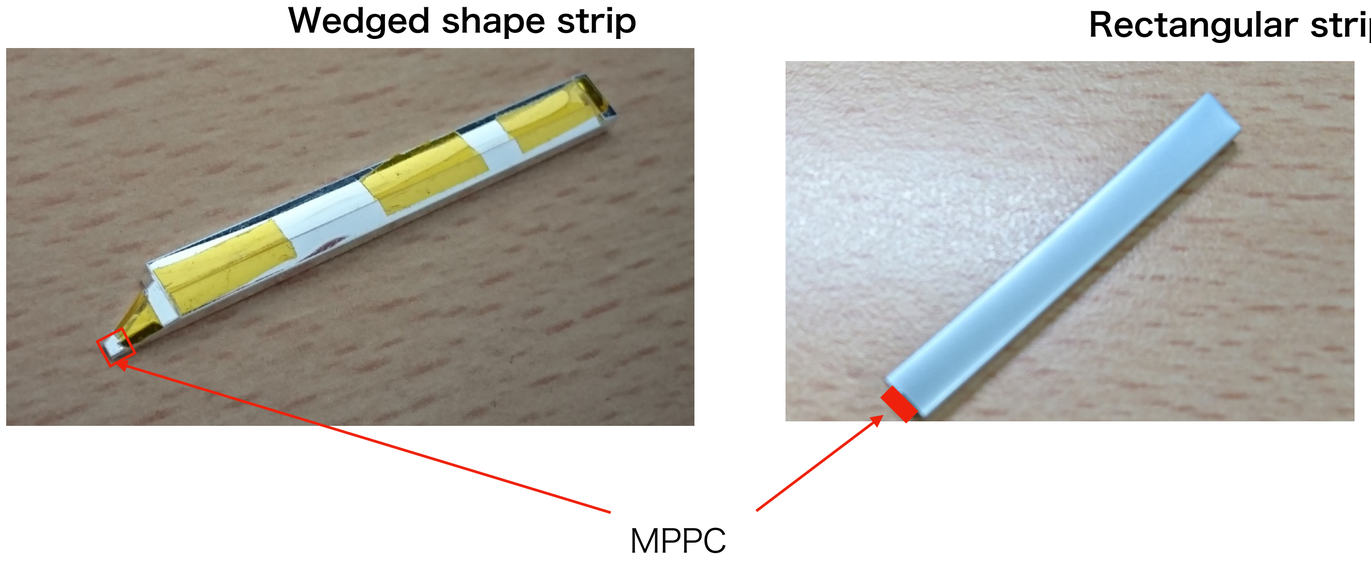




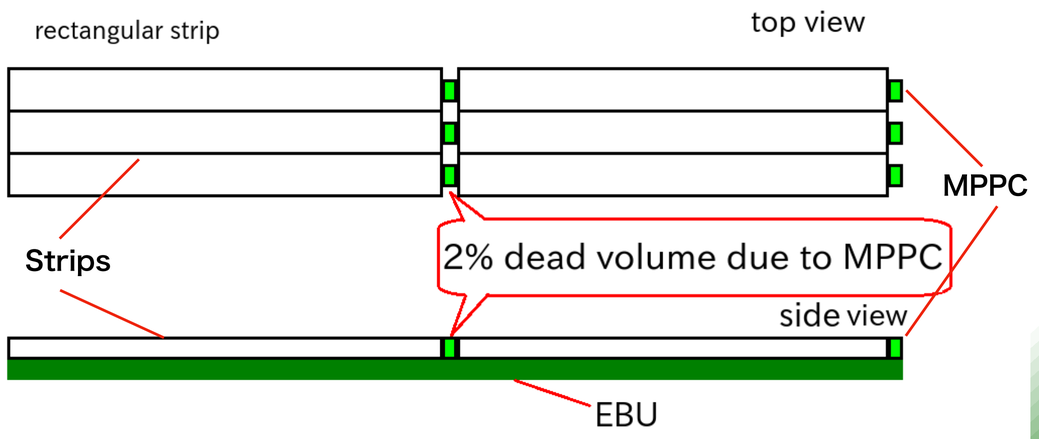


Side readout layer

- Rectangular strip made of EJ204
- Readout from side of strips
- 30% larger light yield than bottom readout
- 2% dead volume due to MPPC

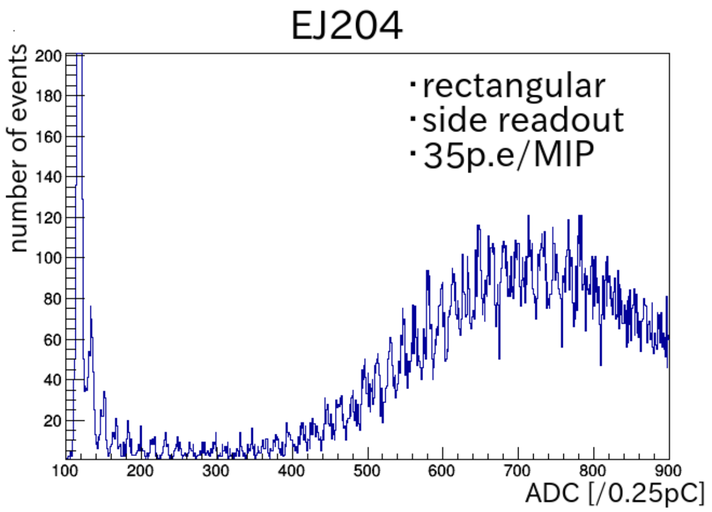


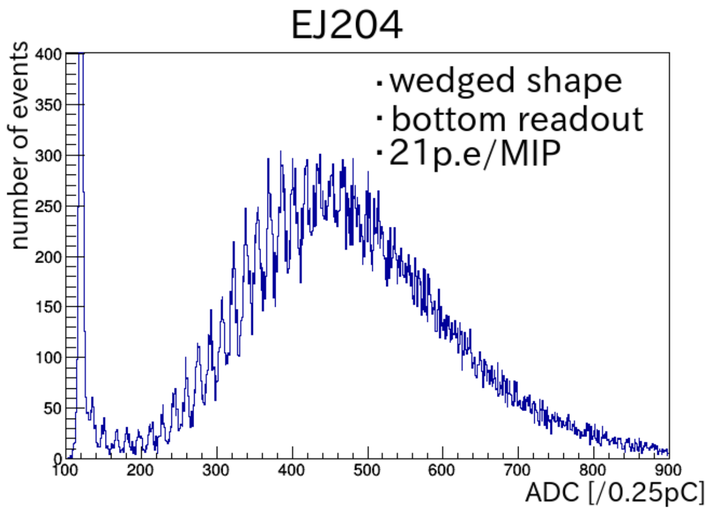
Side readout design



Readout design

- Measured with 15 μm MPPC
- CAMAC readout
- Side readout design has 30% larger light yield than bottom readout design

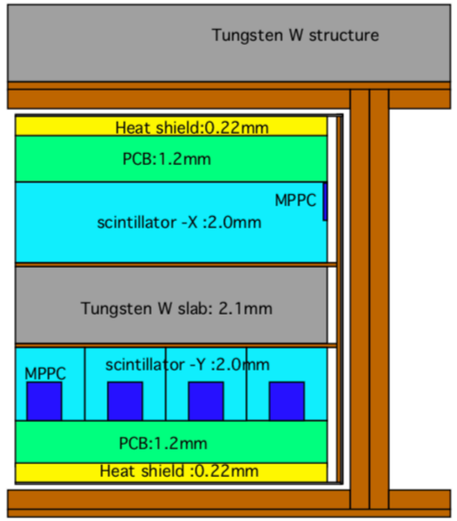




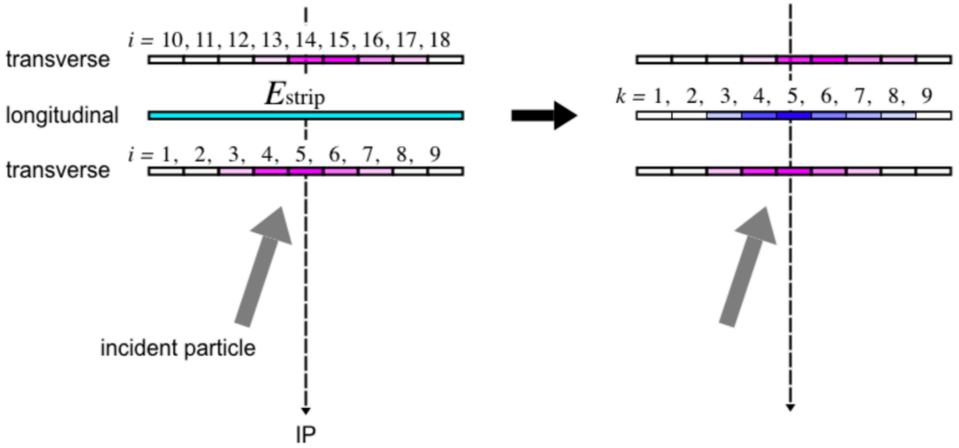
Strip Splitting Algorithm (SSA)

- Scintillator strips in neighboring layers are arranged orthogonally each other
- Split each scintillator into 9 virtual cells along its length
- Energy deposit is weighted by using neighbor layers
- Longitudinal position is set to a virtual cell corresponding to an energy weighted mean of strip positions in the neighboring layers

ScECAL

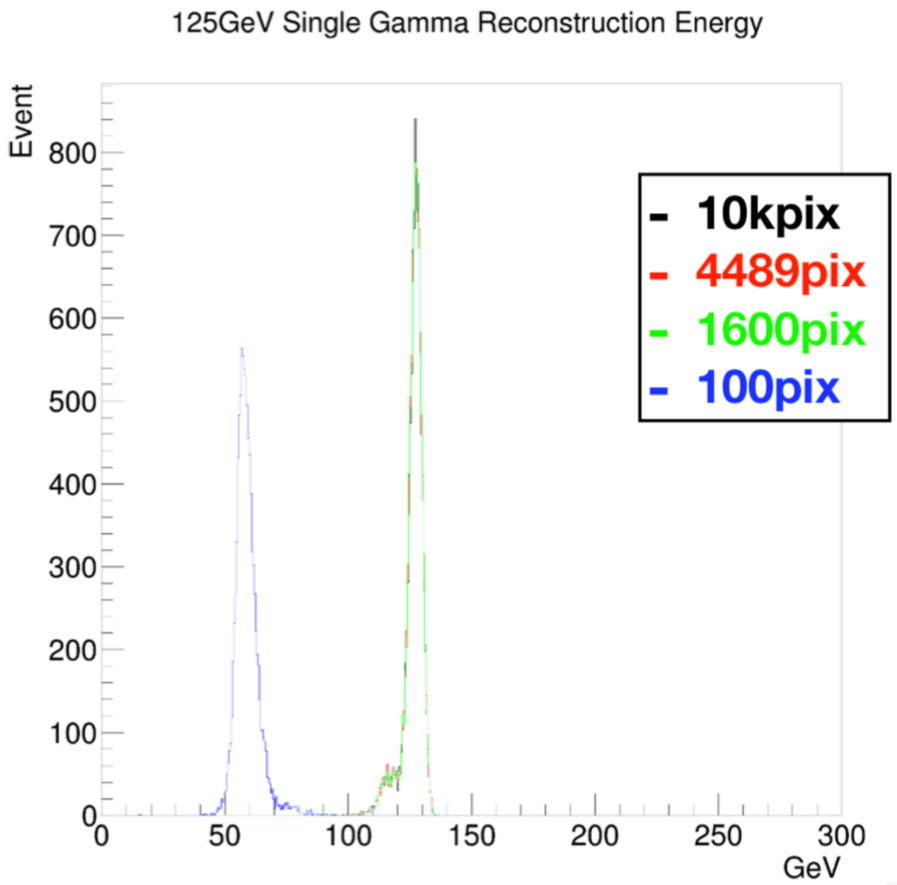


SSA



Saturation effect of MPPC

- Simulation study in 125GeV gamma with ILCSoft
- large difference is not seen between 10μm and 15μm in this result
- study on 250GeV gamma is on going



Simulated by Terada

Response curve of 15μm MPPC

- Fitting function:

$$N_{out} = N_{NLO} \times \frac{\beta + 1}{\beta + \varepsilon N_{in}/N_{LO}}$$
$$N_{NLO} = N_{LO} + \alpha N_R$$
$$= N_{LO} + \alpha(\varepsilon N_{in} - N_{LO})$$
$$N_{LO} = N_{pix} \times (1 - e^{-\varepsilon N_{in}/N_{pix}})$$

- K. Kotera et al., “Describing the response of saturated SiPMs ”, arXiv:1510.01102v4 (2016).