Study on SiPM misalignment in scintillator strip

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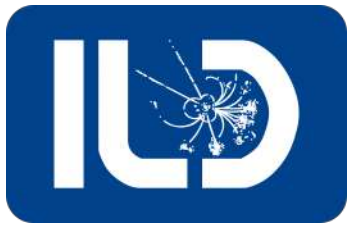
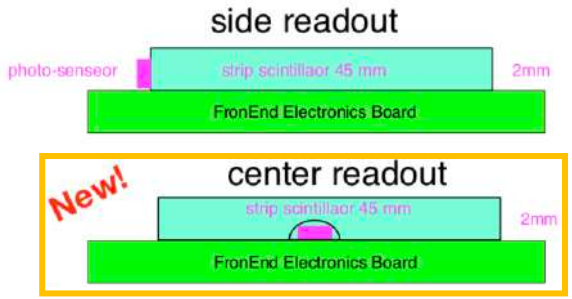
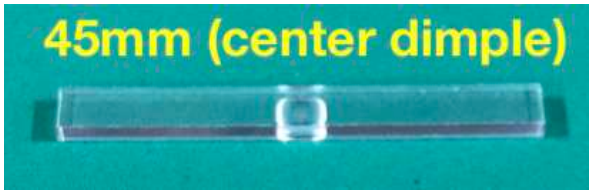


Sc-ECAL

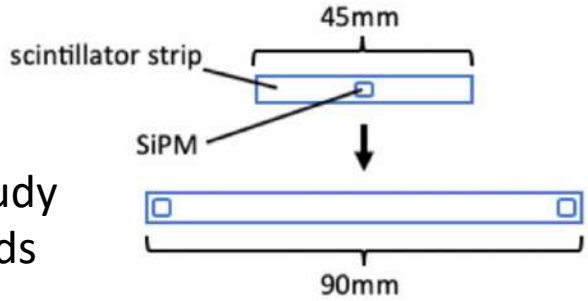
- ECAL concept based on strip-shaped plastic scintillator readout by SiPM
- Virtual $5 \times 5\ \mathrm{mm}^2$ cell segmentation can be realized by strip x-y configuration
- Options for strip-SiPM optical coupling



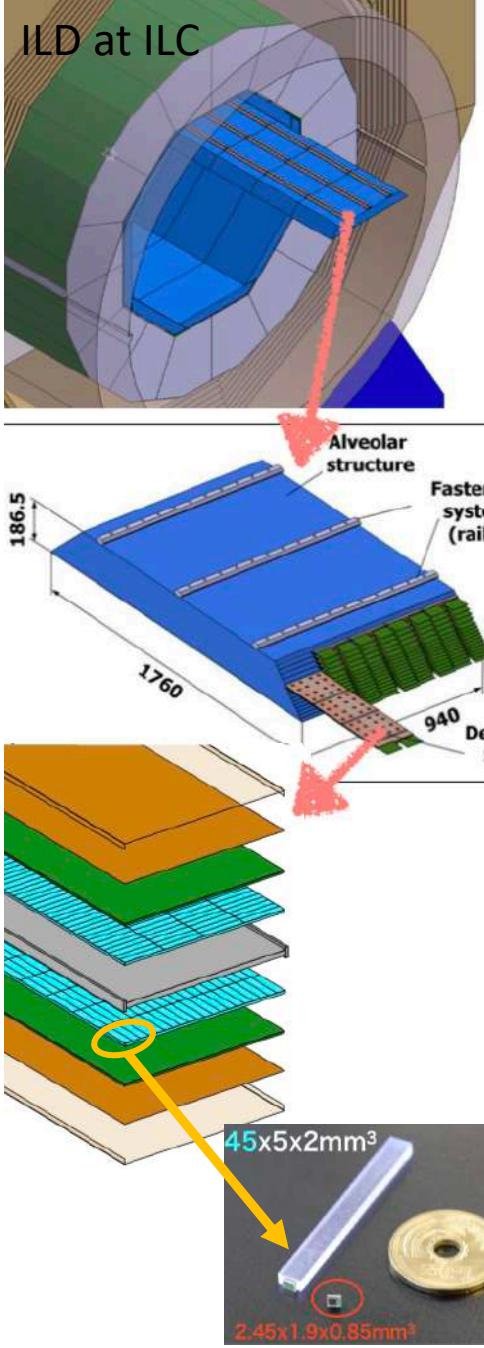


➡Center dimple readout is baseline option

- Double SiPM readout



➡ Another readout option under study
➡ Readout by two SiPMs at strip ends

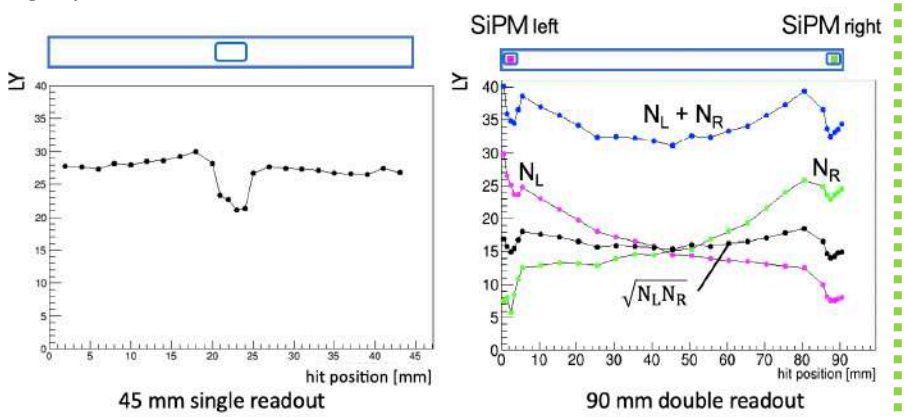


Double SiPM readout

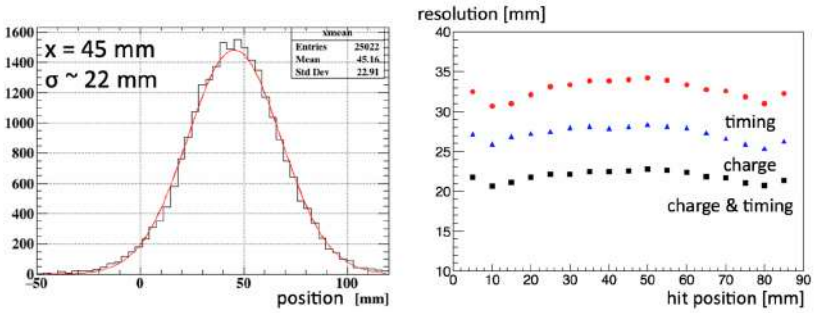
- Possible advantages
  - Eliminating noise by taking coincidence between two SiPM readouts
  - Higher light yield than single readout by summing two SiPM readouts
  - Even lower light yield for each SiPM (➡ less saturation)
  - Still operational even if one of SiPMs is dead

Measured performance

Light yield

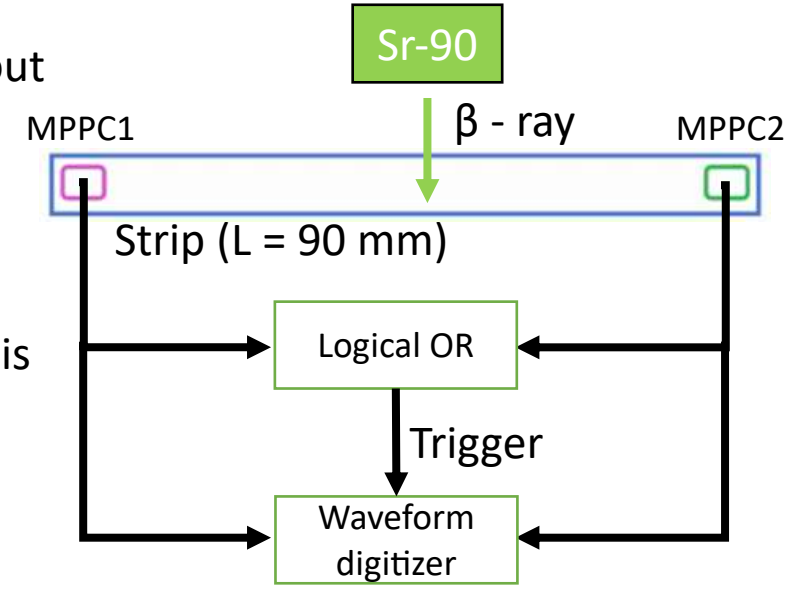


Position resolution



Double SiPM readout

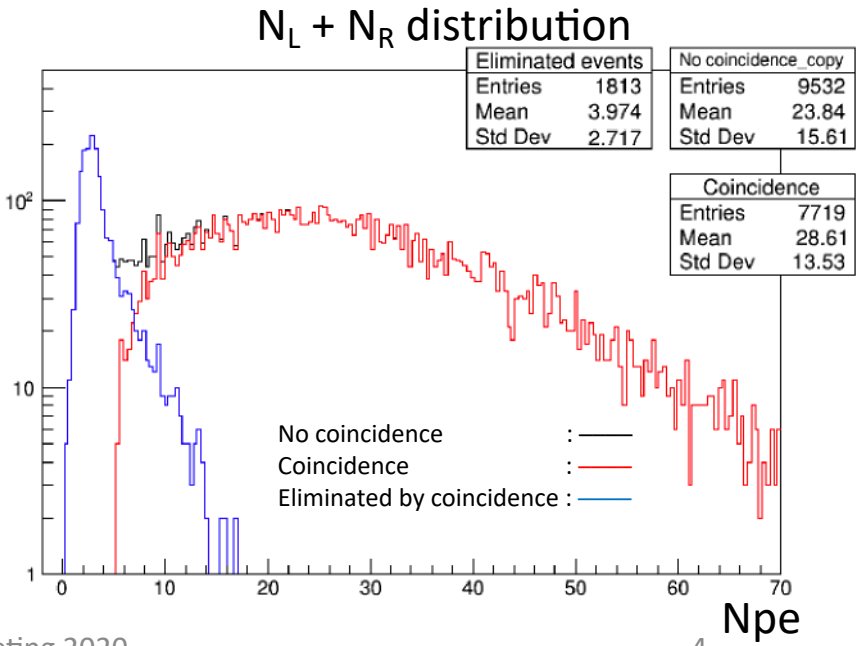
- Performance of noise suppression with double readout
  - ➡ Irradiated by Sr-90
  - ➡ Self trigger with low threshold at 1.5pe for each SiPM, taking logical OR
  - ➡ Taking coincidence with $|\Delta t|<2$ns in offline analysis



- Noise events are completely eliminated

- Low energy β-rays from Sr-90 near pedestal successfully detected

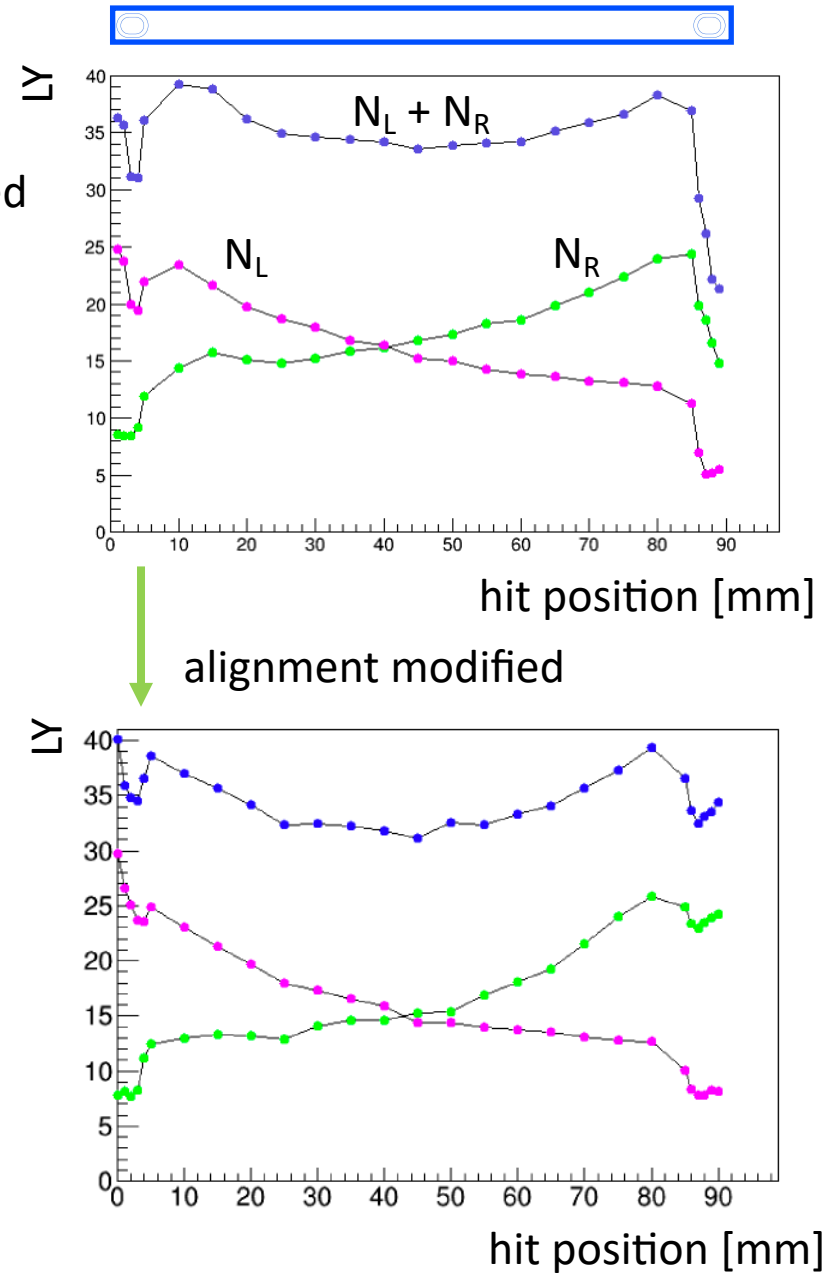
- Further studies on performance for double SiPM readout are in progress



Effect of strip-SiPM misalignment

- Asymmetric distribution of light yield was observed in performance tests of double SiPM readout

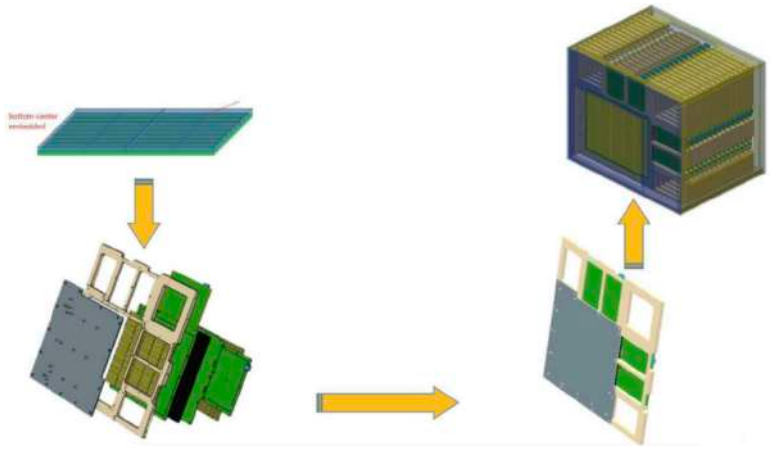
➡ Improved after modifying setup alignment

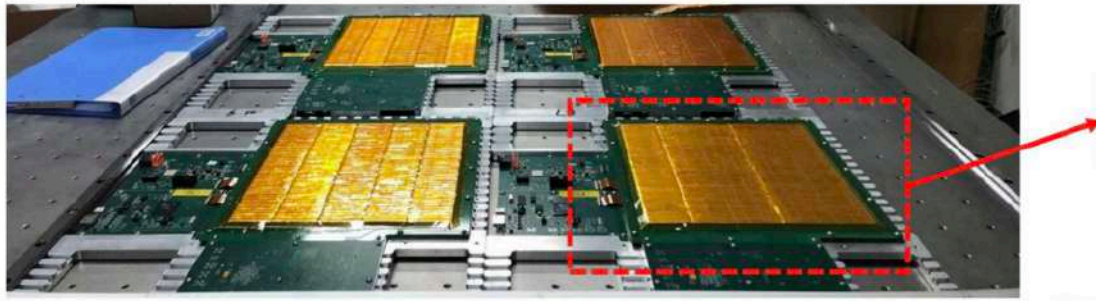


ECAL technological prototype

- Technological prototype for Sc-ECAL is constructed as a joint effort with Chinese groups working on CEPC

  ➡ Full 32 layers
  ➡ ~ 6000 channels in total
  ➡ Assembly is finished and test beam in DESY at 2021

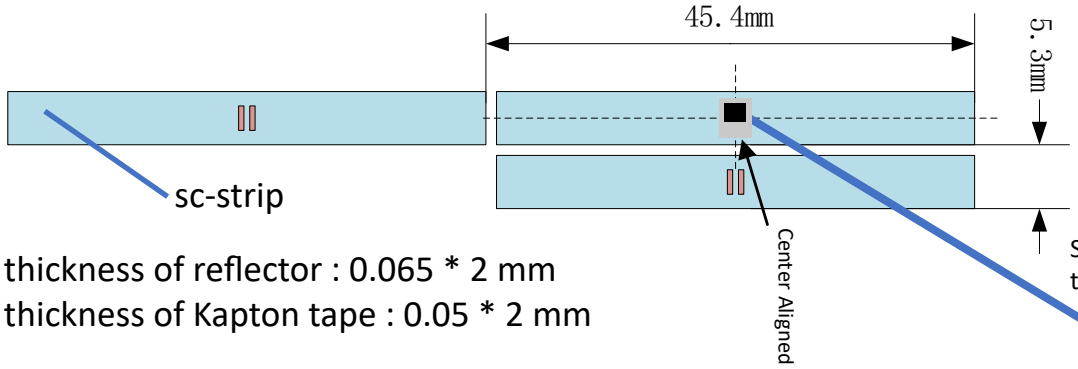




Double readout layers will be also tested

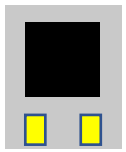
Possible SiPM-strip misalignment at prototype

- Layout of strips on readout board (ECAL Base Unit, EBU)



thickness of reflector : 0.065 * 2 mm
thickness of Kapton tape : 0.05 * 2 mm

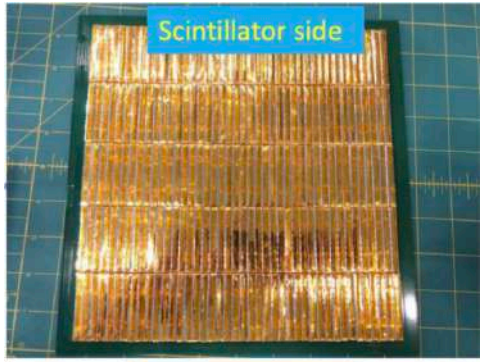
SiPM is aligned perpendicular to longitudinal direction

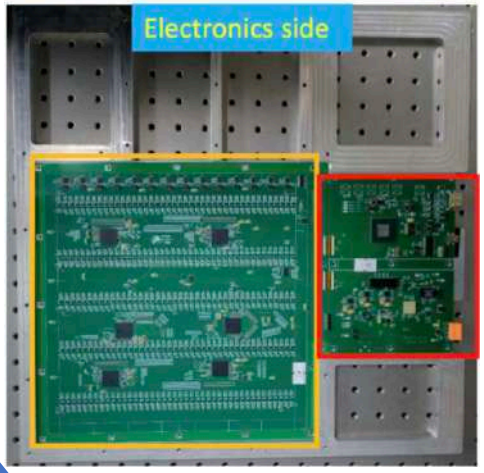


- Each strip wrapped with ESR film (2 x 65 µm-thick) and Kapton tape (2 x 50 µm-thick)

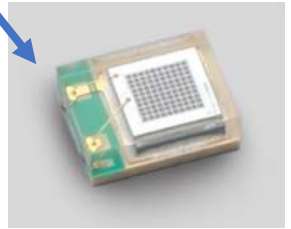
  ➡ Gap between strips up to 0.2mm
  ➡ Possible shift of strip assembly as a whole?

- The effect of strip-SiPM misalignment on the light yield distribution is investigated by both simulation and measurement



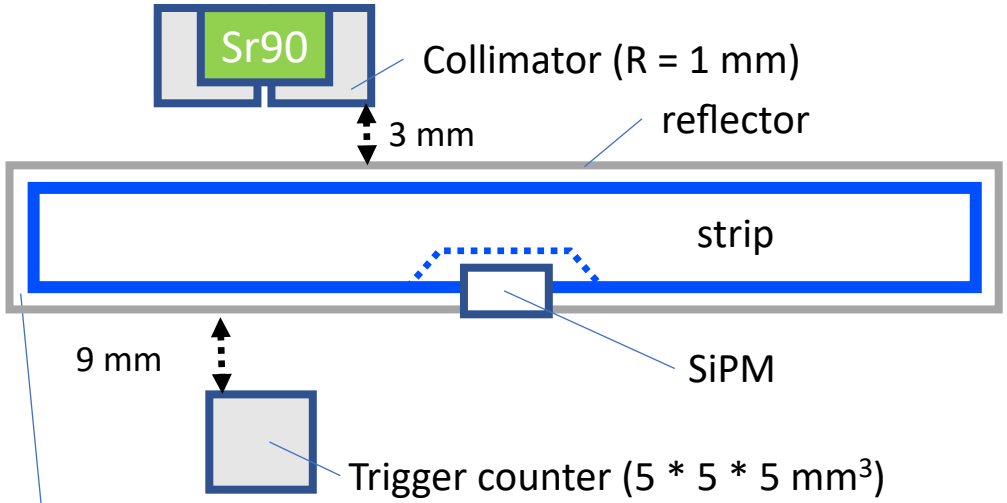


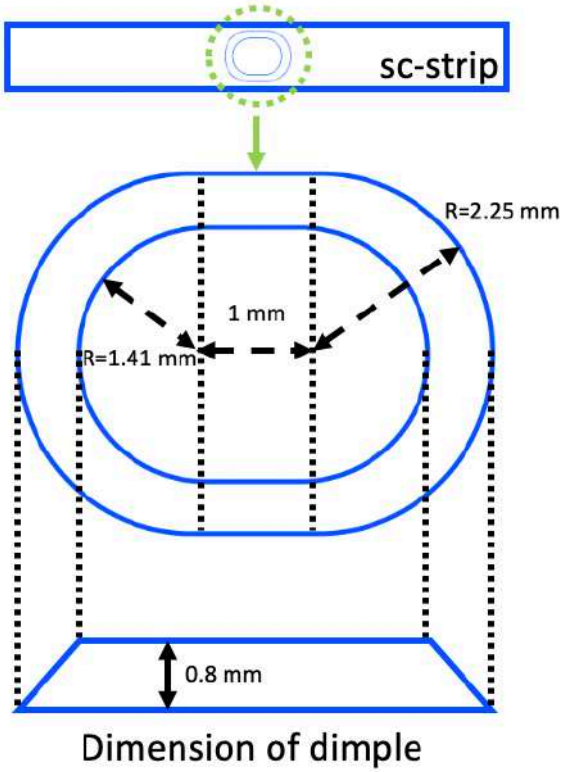
ECAL Base Unit (EBU)



Used SiPM
MPPC : S12571-015P
(1 x 1 mm^2 15µm-pixel)

Simulation setup

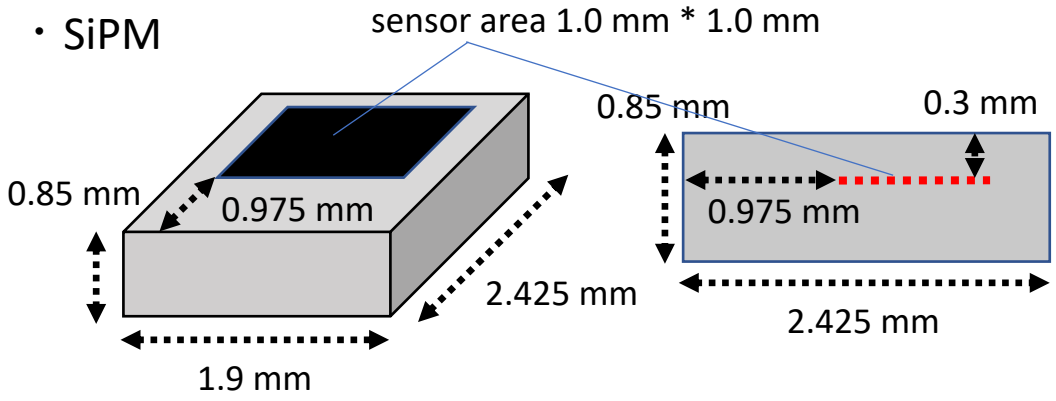


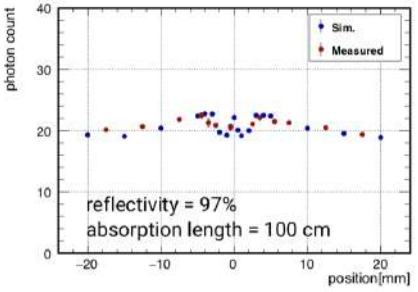


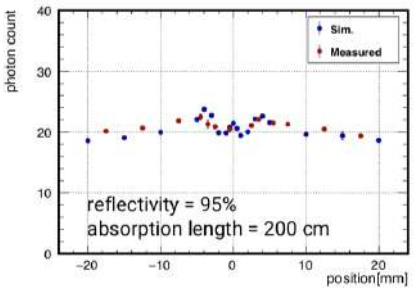
Dimension of dimple

- Air gap between strip and reflector : 0.05 mm

- SiPM







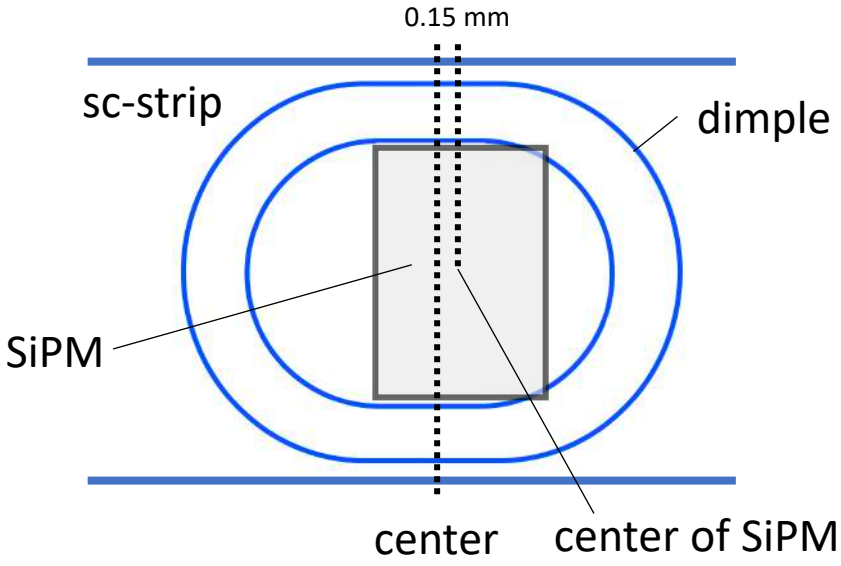
Optical photon simulation parameters

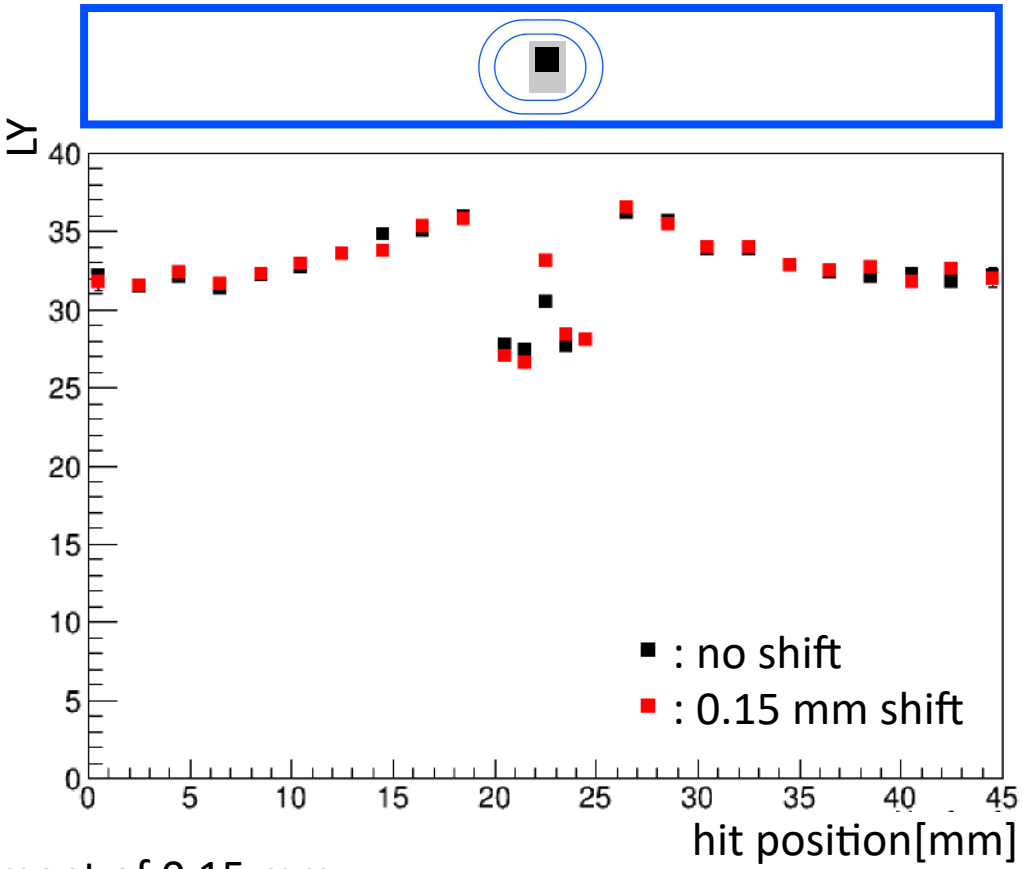
- Reflectivity of reflector : 96 %
- Fresnel reflectance : 95 %
- Refractive index of scintillator : 1.58

These parameters were optimized by T. Mogi (ref. LCWS2019)

Simulation result : horizontal misalignment

- The SiPM can move maximum ~ ±0.15 mm in dimple if there is no extra gap between the scintillator and PCB

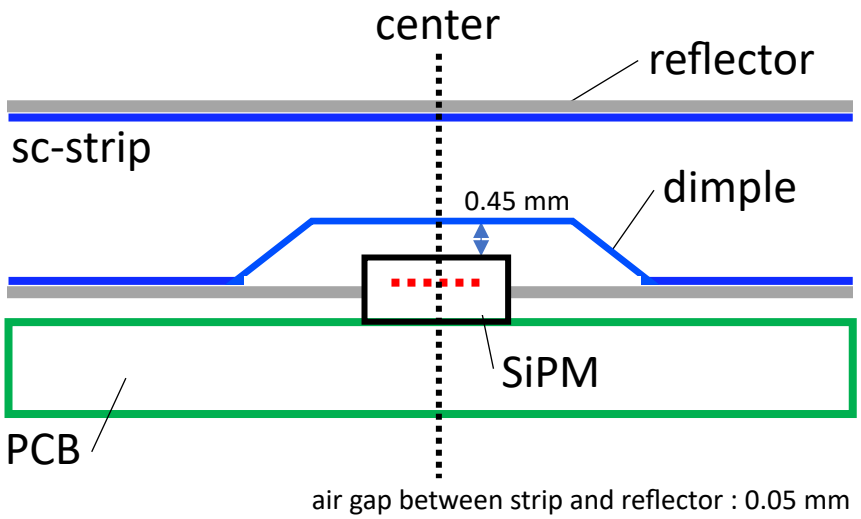


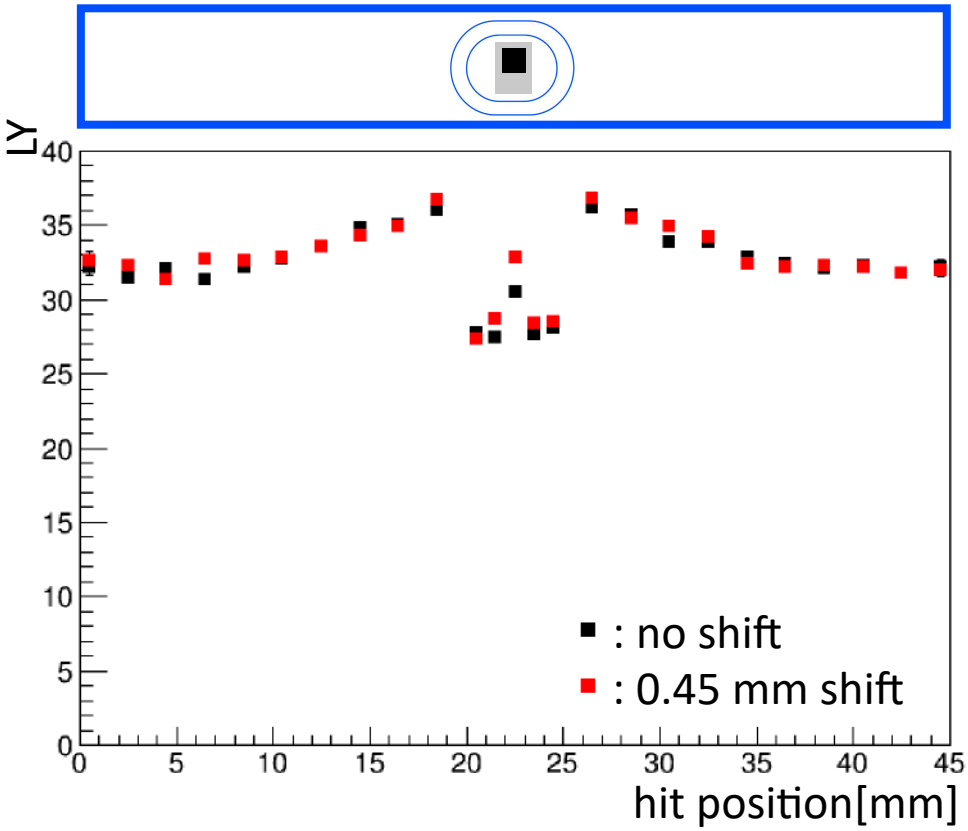


- No significant effect of horizontal misalignment of 0.15 mm

Simulation result : vertical misalignment

・ Possible vertical misalignment up to ~ 0.5 mm



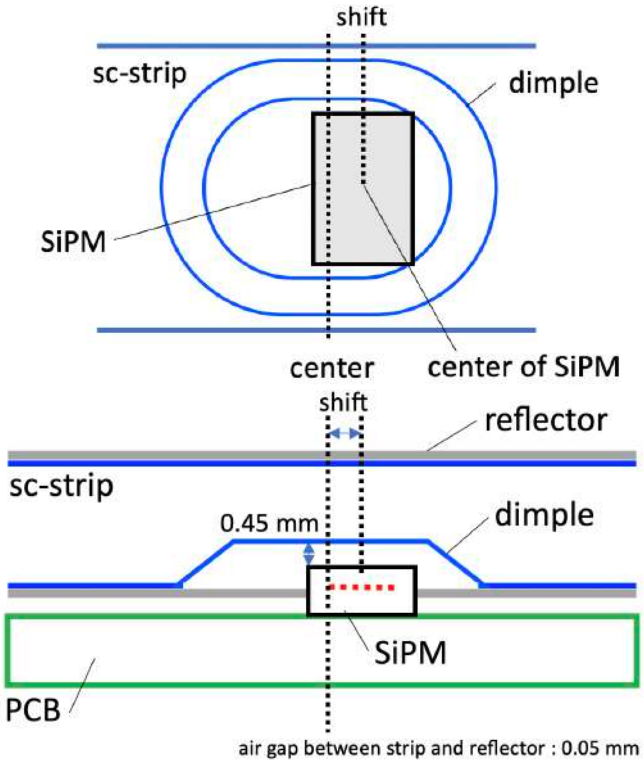


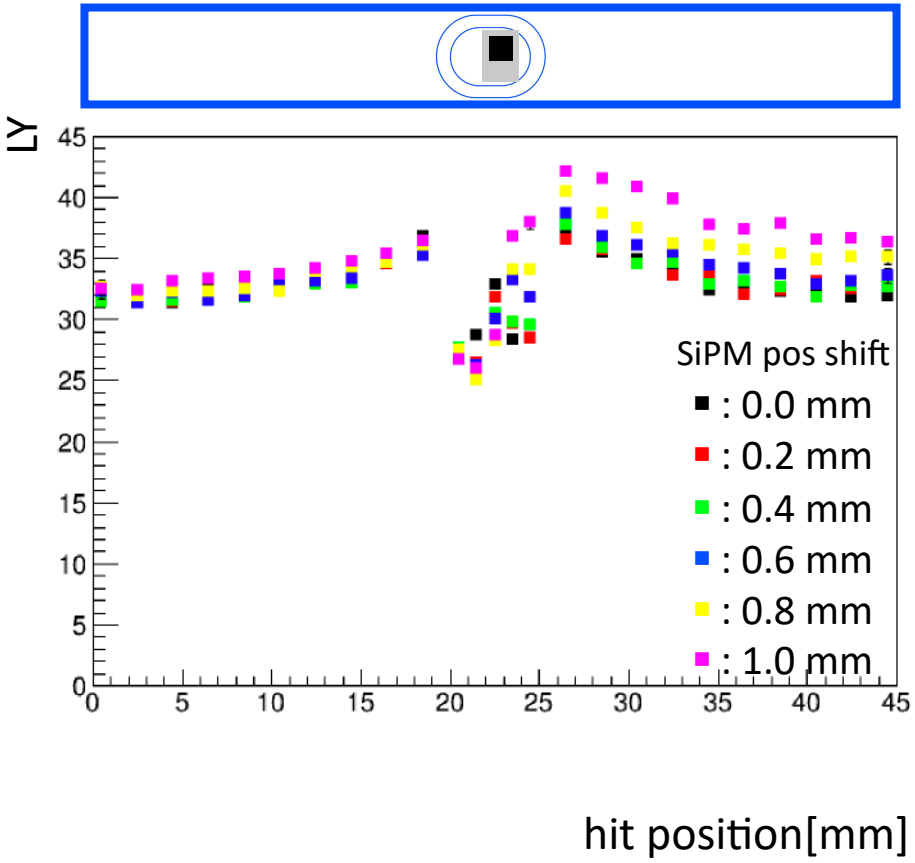
・ No significant effect with vertical misalignment of ~ 0.5mm

Simulation result : combination of horizontal and vertical misalignment

- SiPM package can move horizontally more in the dimple together with vertical shift
  ➡ Up to ~ ± 1 mm with ~ 0.5 mm vertical shift

- Horizontal shift scan up to 1 mm with vertical shift of 0.45mm
  ➡ **The behavior of LY around at censor becomes asymmetric as the shift becomes larger**



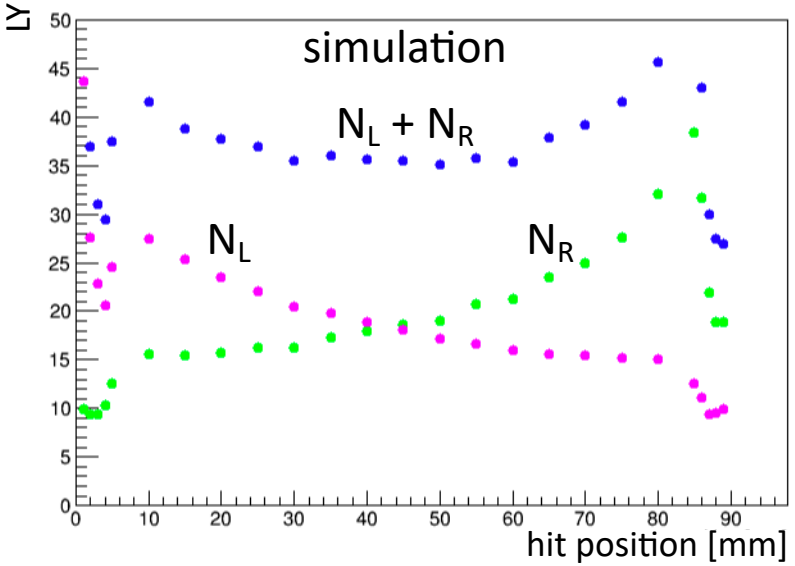


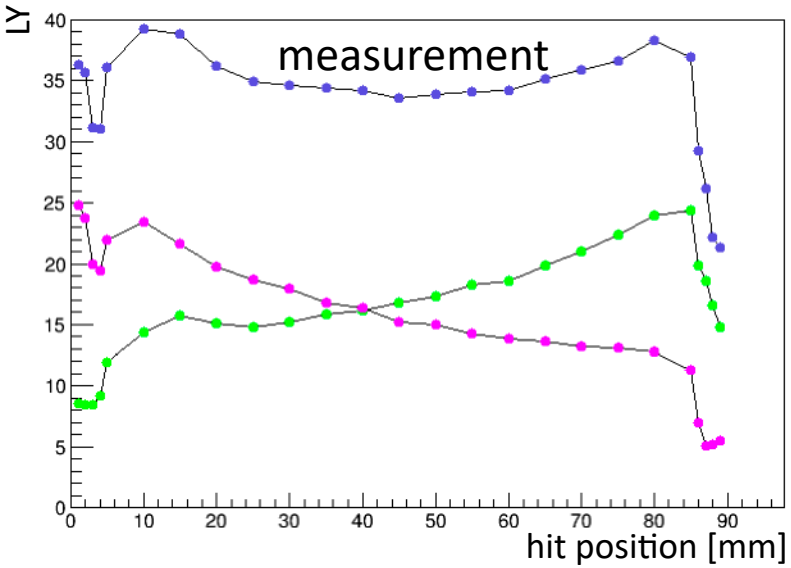
Simulation result : double SiPM readout

- Horizontal shift of 1 mm and vertical shift of 0.45mm

  ➡ Simulation reproduces the asymmetric distribution observed in the measurement

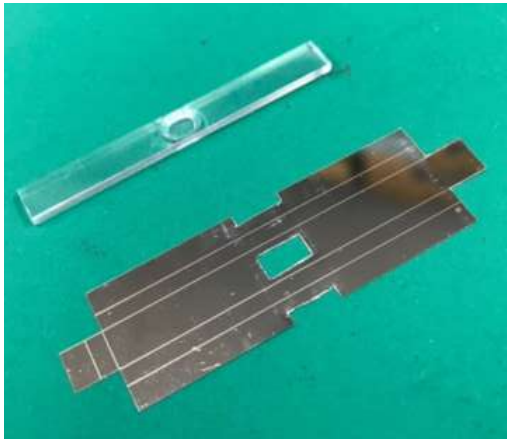
- LY distribution for double SiPM readout seems more sensitive to misalignment compared to single readout



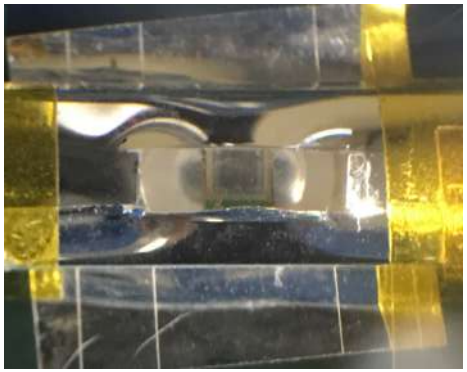


Measurement setup

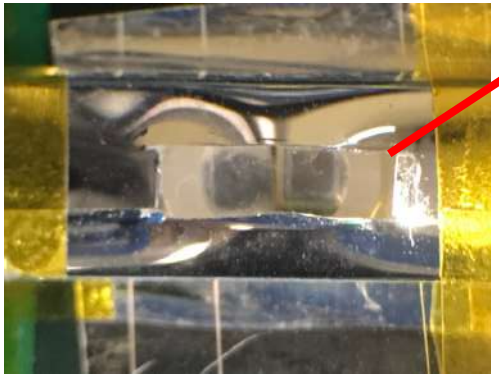
- Design of reflector for misalignment measurement
- Hole on the top side reflector to check the SiPM shift before the measurement



SiPM at center

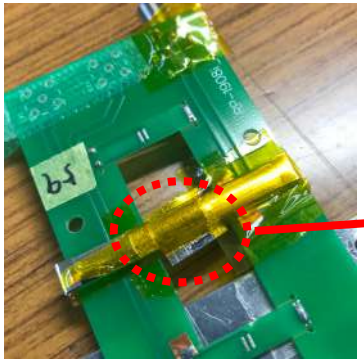


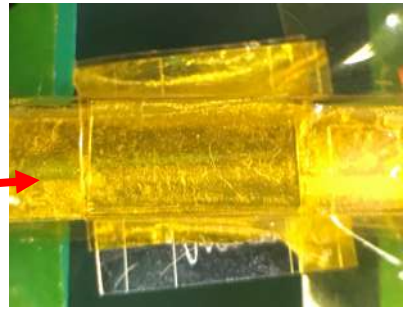
SiPM at 0.7 mm from center

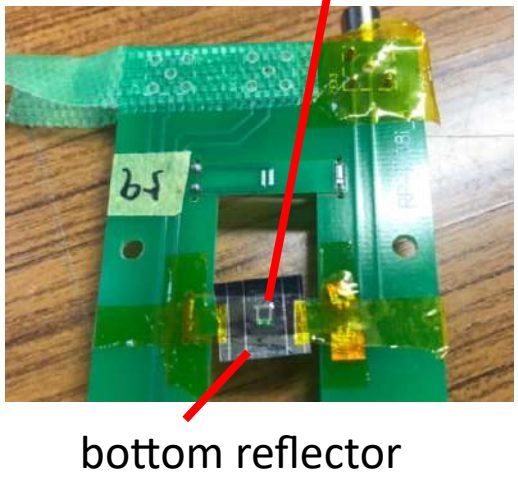


SiPM window

➡ Covered with additional reflector during the measurement



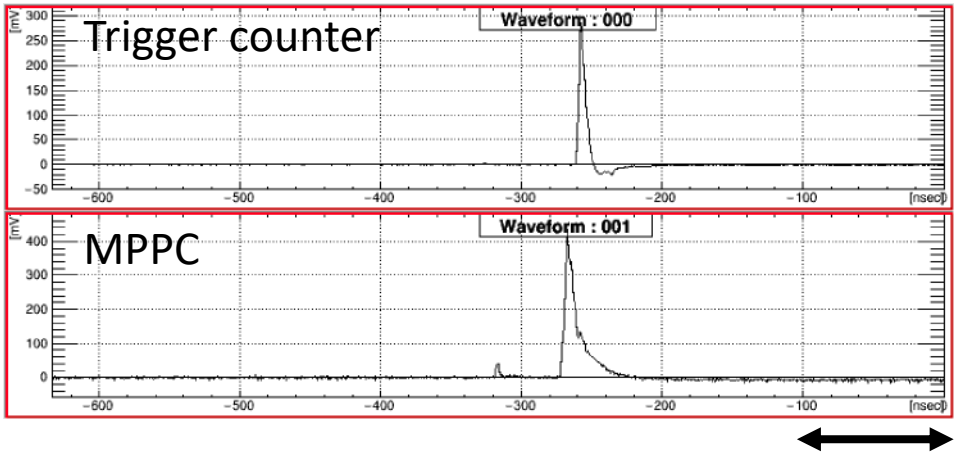




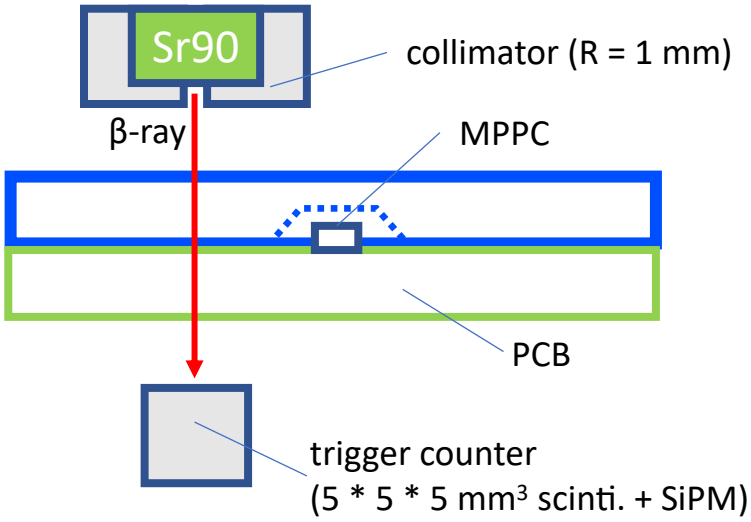
- Separate reflector at the bottom side to cover SiPM package

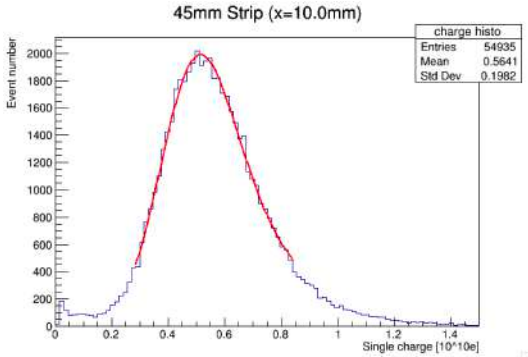
Measurement setup

Plastic scintillator：EJ-212
Reflector：ESR2 (laser-cut)
MPPC：S12571-015P (1 x 1 mm^2 15μm-pixel)
V_{op} : ~ 68V
Analysis : Waveform digitizer

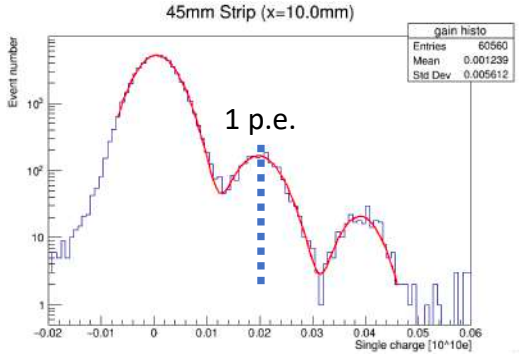


100 ns





charge



dark noise spectrum

Light yield = (charge peak)/(single p.e. charge)

Measurement Results

①SiPM package position shift ~ 0.0 mm

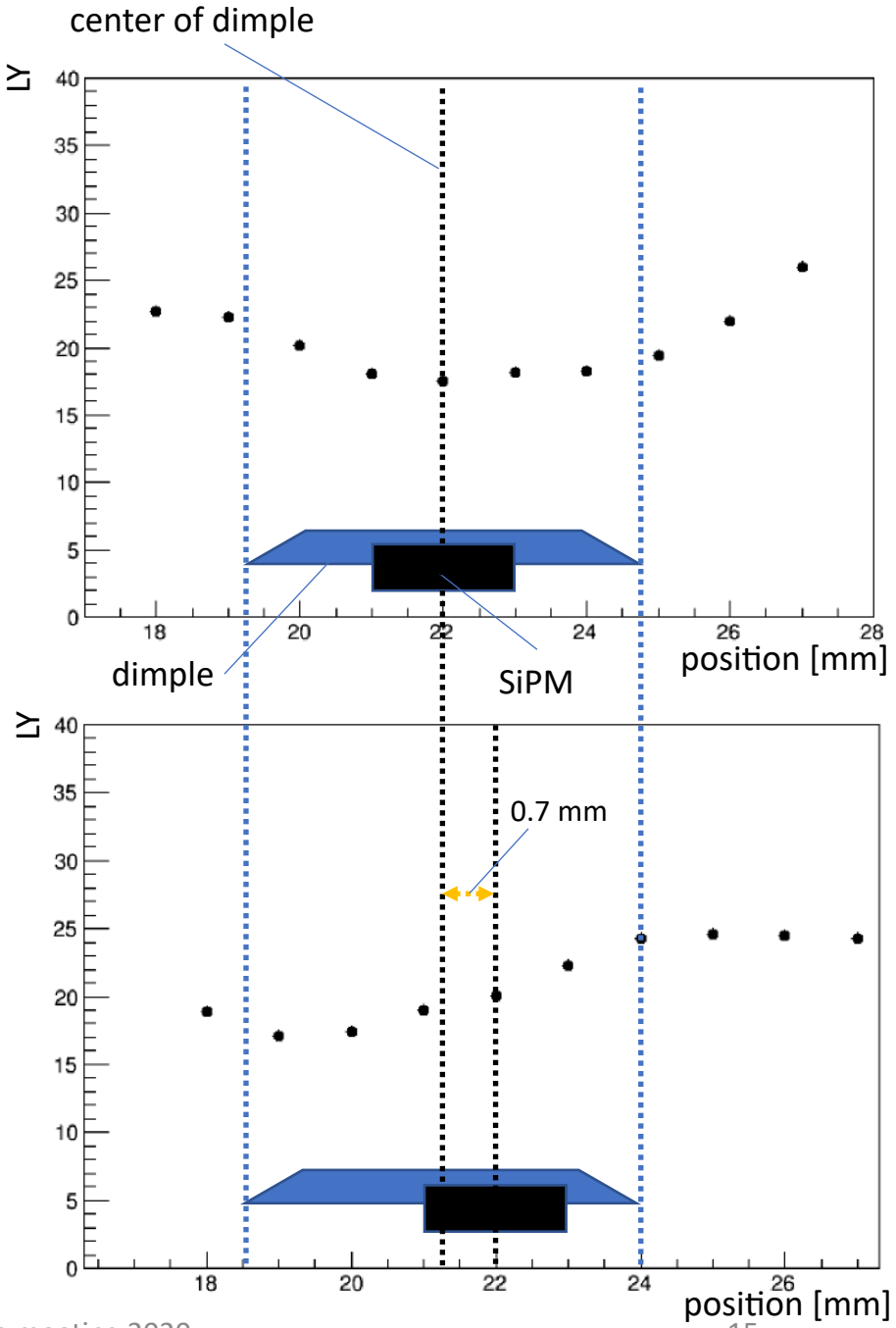
➡ Symmetric LY distribution

②SiPM package position shift ~ 0.7 mm

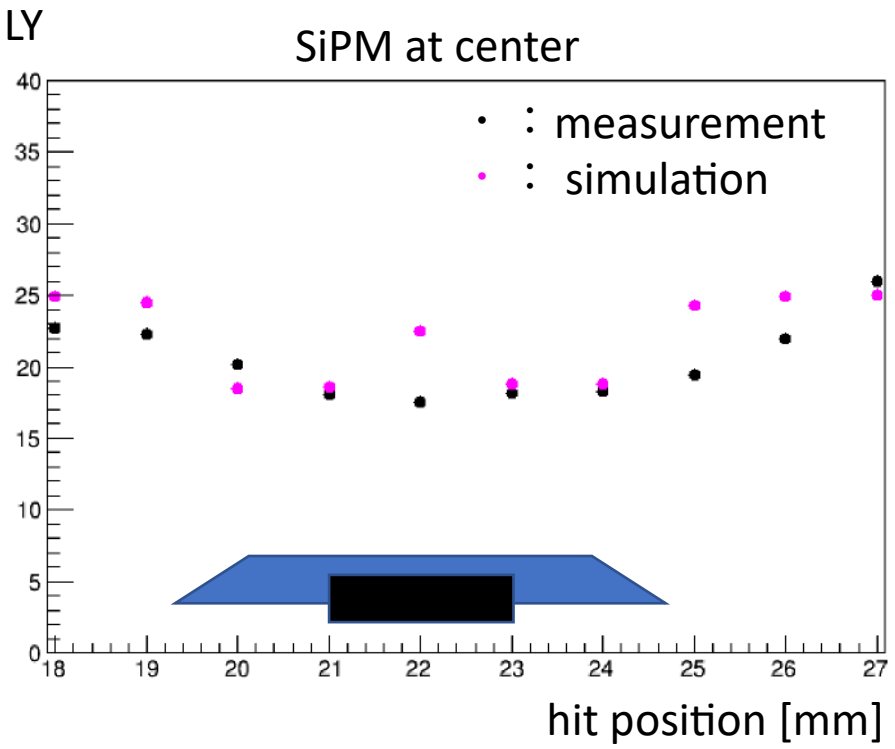
➡ **Asymmetric LY distribution**

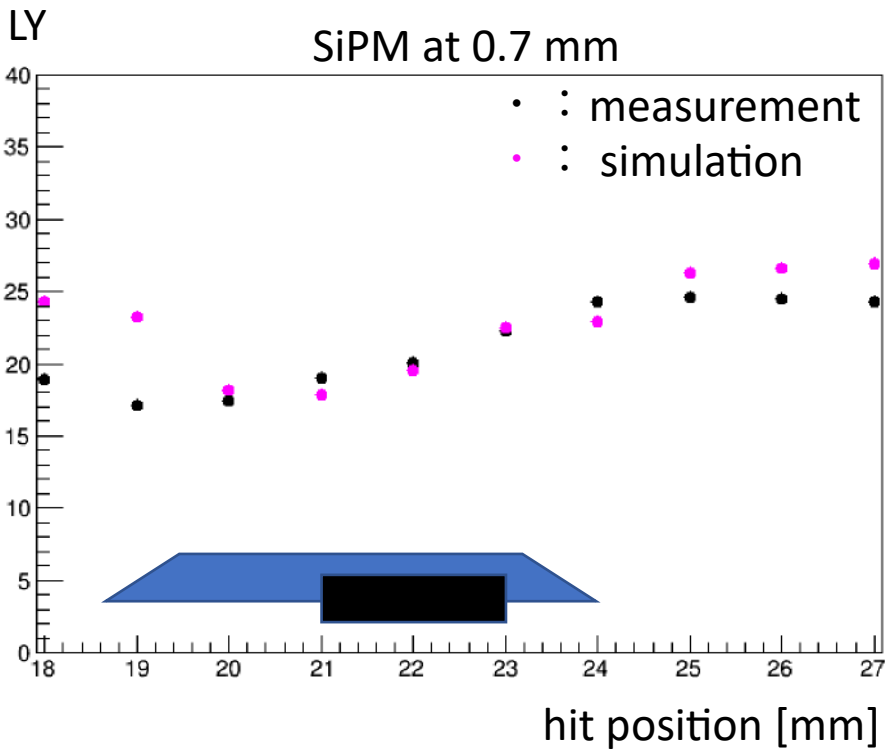
・The measured average light yield is ~ 23

➡ lower than previous measurements (~ 30)
Effect of top hole of reflector?



Measurement Results : Comparison with Simulation





- N.B. LY in simulation is normalized to data
- Similar behavior between simulation and data
- Peak structure around SiPM in simulation is not observed in data
  ➡ Smeared out?

Summary and prospects

- The noise suppression by timing coincidence in double SiPM readout was performed
  ➡ Noise and signal events are completely separated

- Effect of possible strip-SiPM misalignment for Sc-ECAL is studied

- Asymmetric LY distribution observed in the simulation with horizontal alignment larger than ~ 0.6 mm

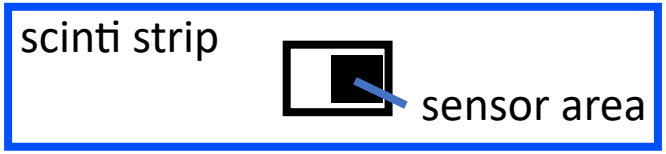
- Same behavior observed in the measurement, though the setup should be improved

- Need further studies

  ➡ Studies with Sc-ECAL prototype
  ➡ Simulation studies on the effect of misalignment on the calorimeter performance

Backup

Simulation of SiPM position effect in dimple



- SiPM package is aligned symmetrical to strip on EBU for large prototype test, but the lab setup is assumed that the SiPM is aligned along the strip longitudinal direction

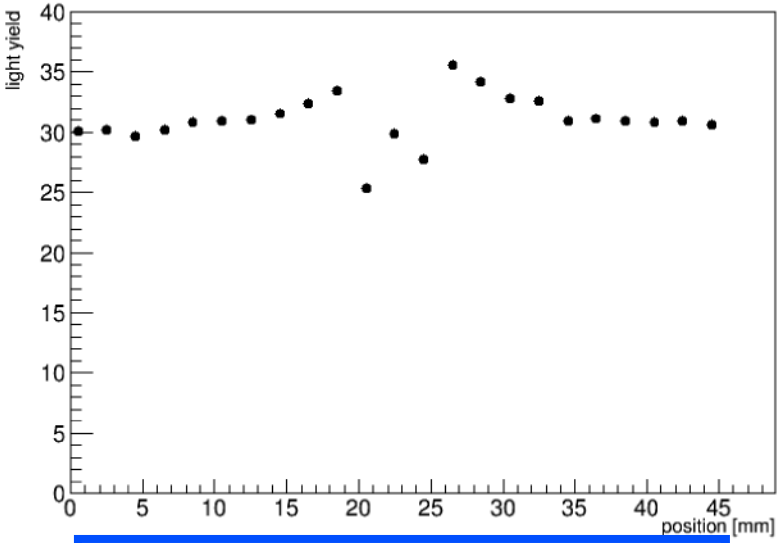
  ➡ Investigate the SiPM package angle effect by simulation

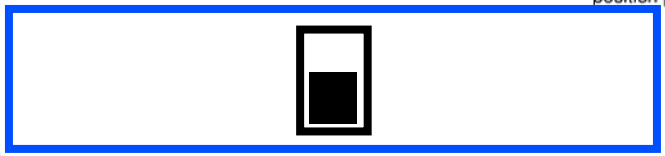
- In 90 deg case, the LY behavior at center (around the MPPC position) is not symmetric

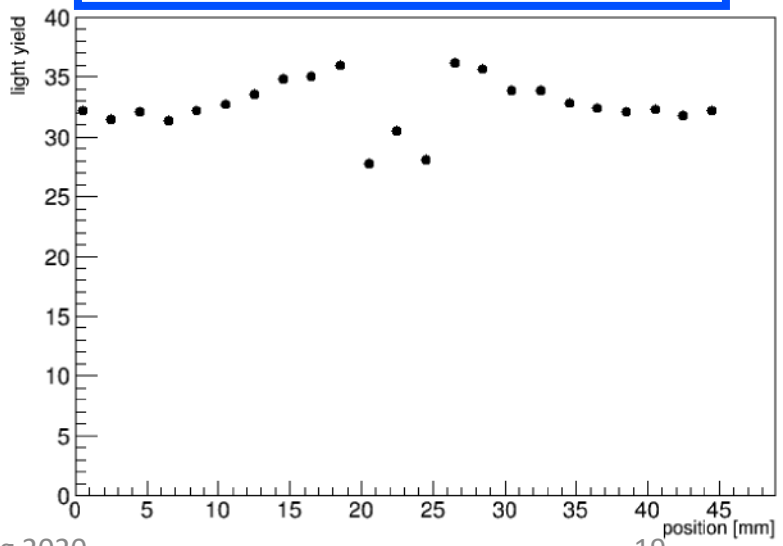
  ➡ LY at right side of the MPPC is higher than left side because of the position of MPPC sensor area

- On the other hand, LY is symmetric in 0 deg case

  ➡ The angle of MPPC package (position of sensor area) can affect the LY around the dimple



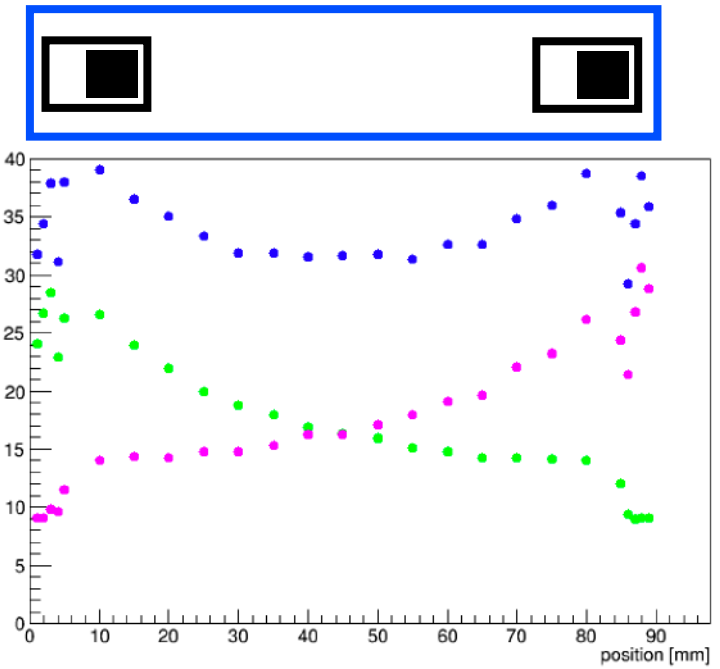




Simulation of SiPM position effect in dimple

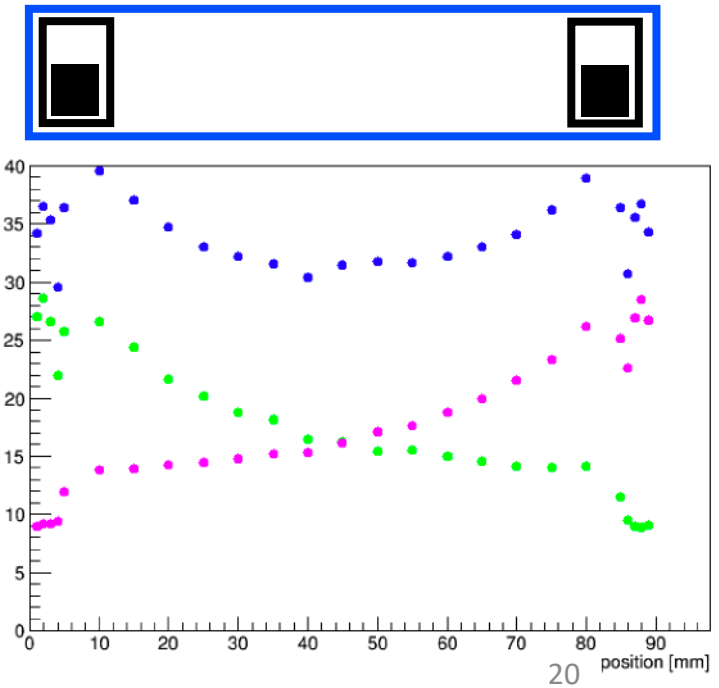
- Double readout case
- In 90 deg case, the LY behavior at each ends are asymmetric

  ➡ LY at the right end is higher than left end's one because of the position of MPPC sensor area



- On the other hand, LY is symmetric in 0 deg case

  ➡ The Angle of MPPC package can affect the LY around the ends

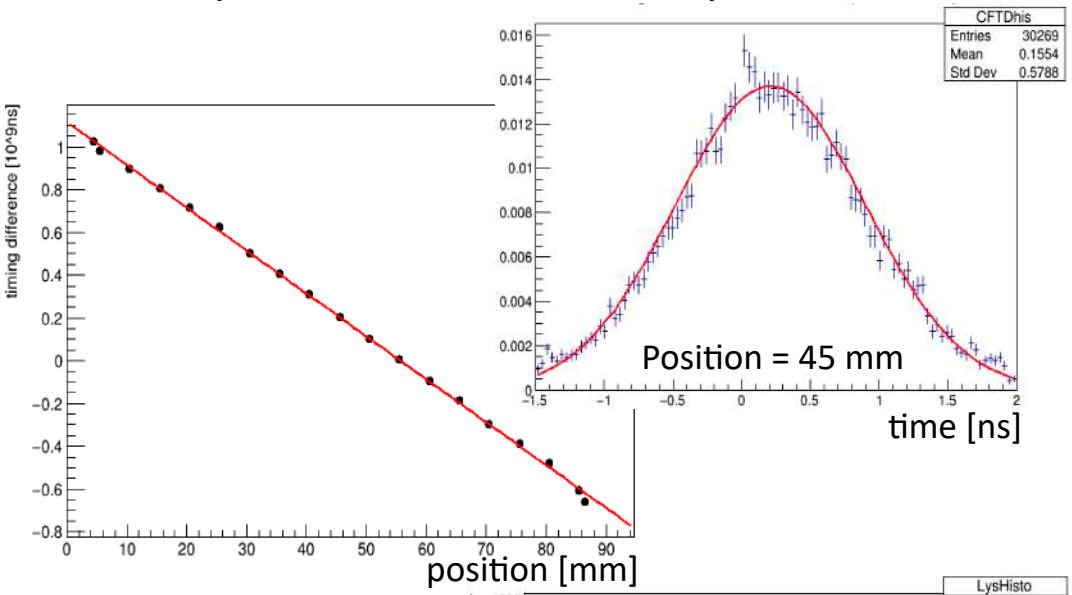


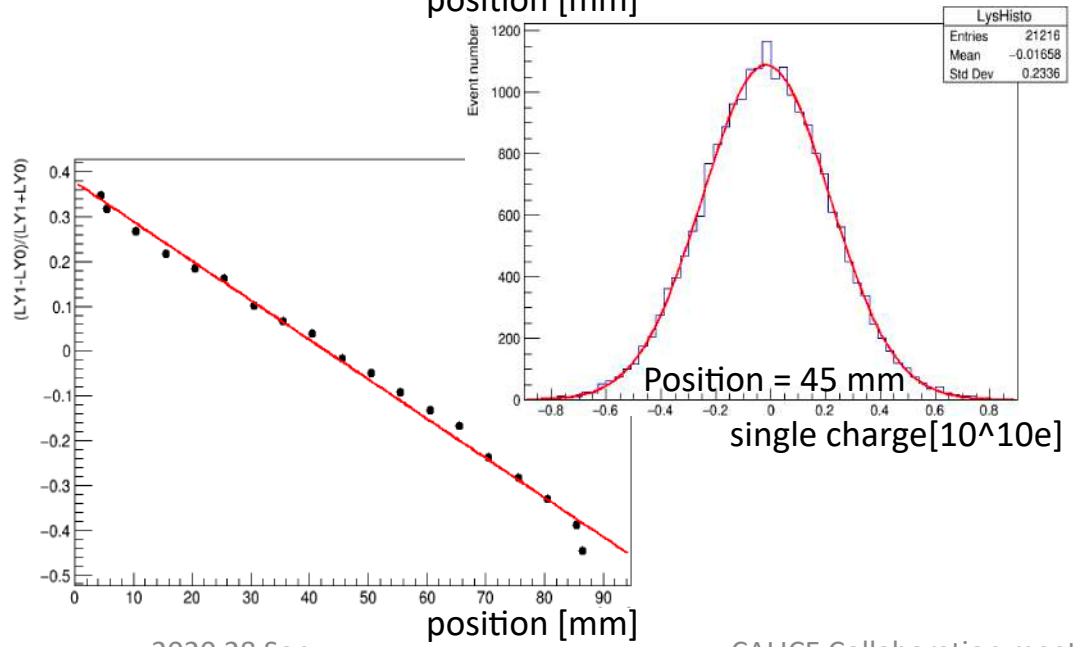
- The SiPM position shift effect on double readout case should be also measured by lab setup

  ➡ Under study

Position resolution analysis of double readout

- The hit position reconstruction by differences in the timing and charge





➡ Convert timing and charge into position by using linear fitting function (red linear lines)

- The position resolution was obtained from converted distribution of timing, charge and weighted mean of them

- weighted mean $x_{mean} = \dfrac{\frac{x_t}{{\sigma_t}^2} + \frac{x_l}{{\sigma_l}^2}}{\frac{1}{{\sigma_t}^2} + \frac{1}{{\sigma_l}^2}}$

$x_{t/l}$: converted position from timing / light yield difference

$\sigma_{t/l}$: position resolution from timing / light yield difference

- This lab. study was performed with high-speed waveform digitizer

➡ Need to improve timing performance of the present electronics of the Sc-ECAL to achieve the same resolution