Simulation study on performance of Sc-ECAL for ILD

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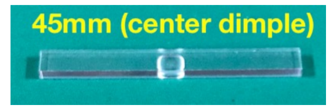
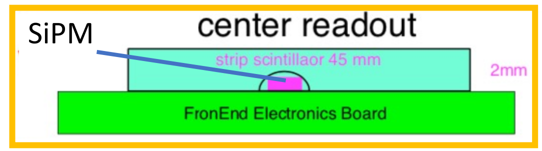
Sc-ECAL

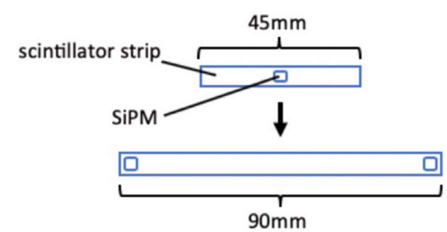
- ECAL concept based on strip-shaped plastic scintillator readout by SiPM
- Virtual $5 \times 5\ \mathrm{mm}^2$ cell segmentation can be realized by strip x-y configuration
  - ➡ # of readout channel can be reduced
  - ➡ High granularity

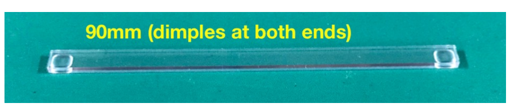


- Options for strip-SiPM optical coupling
  - ➡ Center dimple readout is baseline option

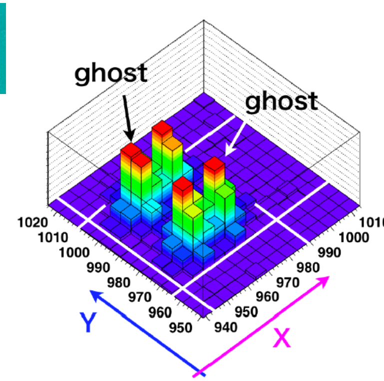


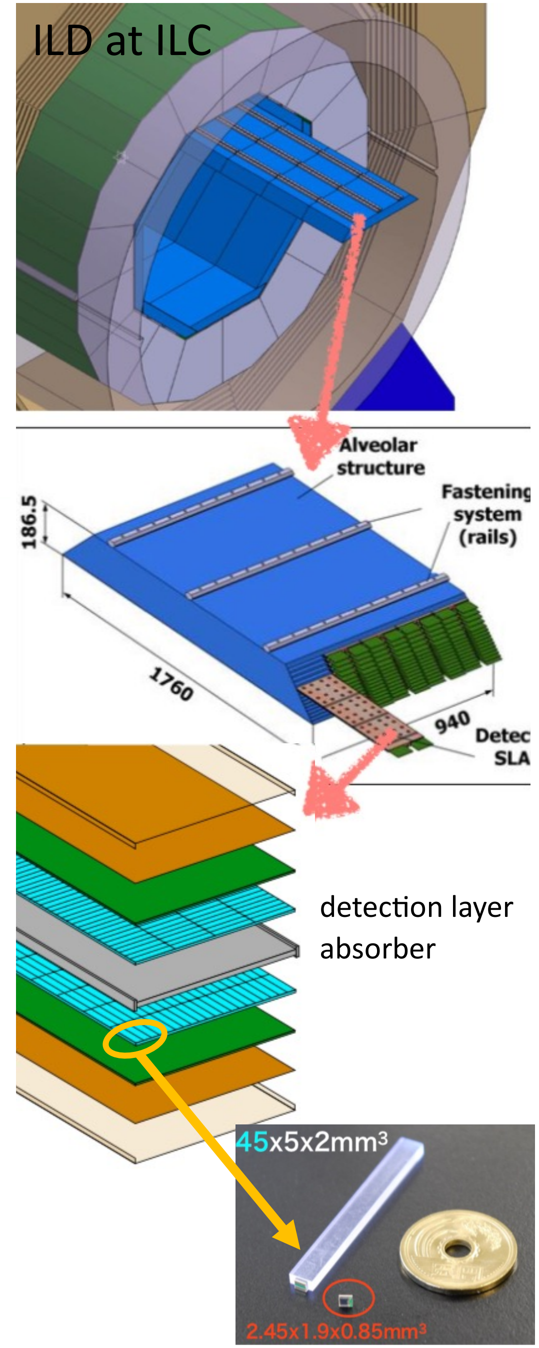
- Double SiPM readout
  - ➡ Readout by two SiPMs at strip ends
  - ➡ Expected to reduce noise by taking coincidence



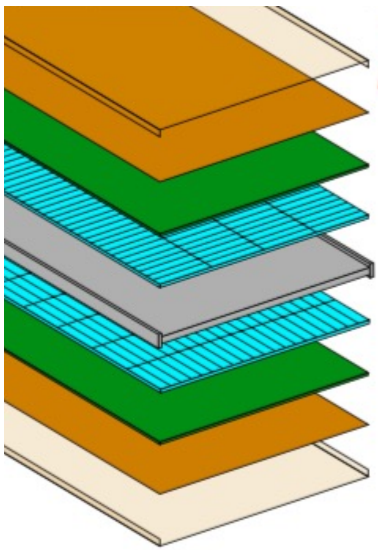


- Ghost hit problem
  - ➡ False signal from simultaneous hits
  - ➡ Expected to be eliminated by double SiPM readout





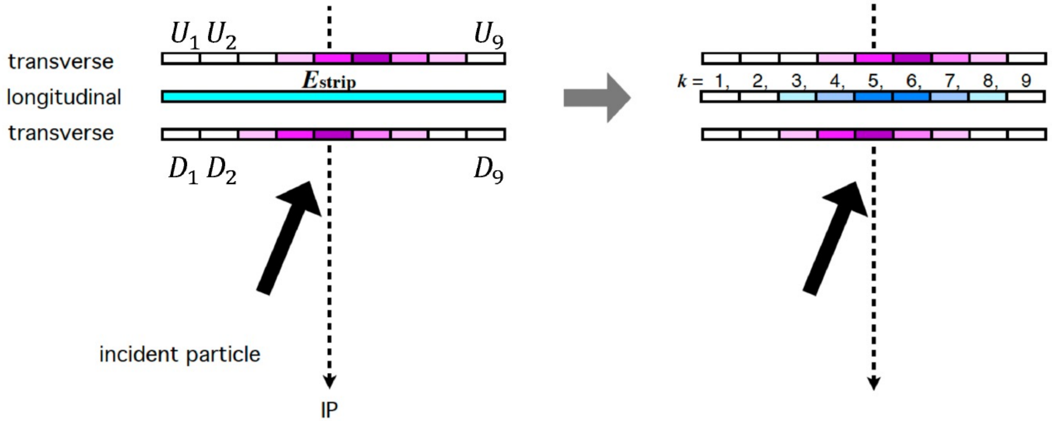
Strip Splitting Algorithm (SSA) in Sc-ECAL



- In SSA, each strip is divided into 5 * 5 mm^2 virtual cells to ensure granularity
- The energy measured in a strip is distributed each virtual cell using hit information of strips on immediately next layers

➡ The distributed energy of k-th virtual cell E_k is

$$E_k = E_{strip} * \frac{U_k + D_k}{\sum_{i=1\sim 9}(U_i + D_i)}$$



K. Kotera

- SSA is applied at reconstruction process

Outline of Sc-ECAL simulation study

- Simulation study on calorimeter performance with realistic conditions is becoming more important

Realistic conditions to be implemented in simulation

➡ Effect of hit position dependence on light yield
➡ Effect of gap/misalignment between strip and SiPM
➡ Performance improvement with double SiPM readout
➡ Light yield measured in Sc-ECAL prototype

- ILC simulation model used in this study

➡ Simulation tool (iLCSoft)
➡ Both ECAL and HCAL are based on plastic scintillator ILD model version (ILD_l5_o3_v02)

- **Topics for today**

➡ **JER evaluation with some realistic strip properties**

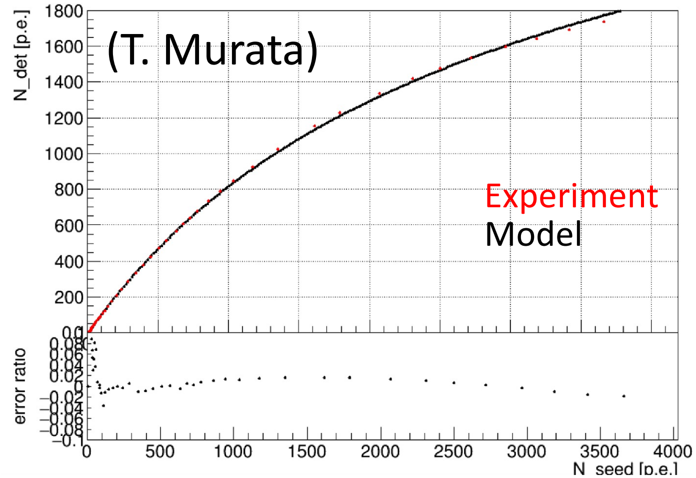
➡ **SiPM saturation model obtained from measurements**
➡ **Position dependence of light yield**

ILD simulation with realistic effects

- **SiPM saturation**
  ➡ Simple saturation model → Saturation model based on recent measurement using UV LED

- **Position dependence of light yield**
  ➡ Scale energy deposit according to position dependence of light yield

SiPM saturation model



Simulation flows

Hit simulation
- Energy deposit (ED)
- Hit position

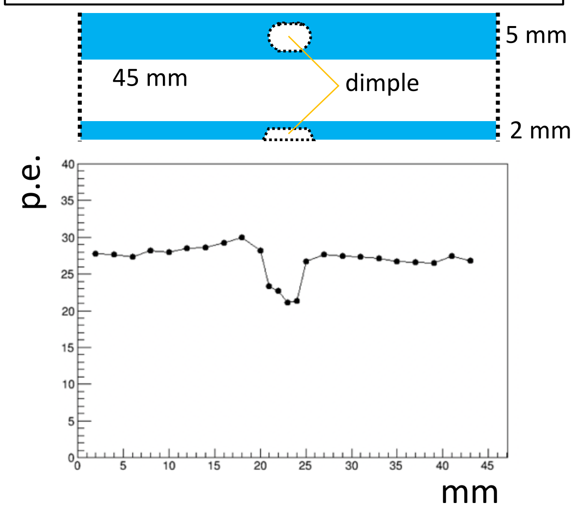
→ (input)
- Position dependence of hit energy
- SiPM saturation

Digitization
- Convert hit data to a signal visible to detector (ED -> photoelectron)

→ (input)
- Correction of hit position dependence
- Resolving saturation

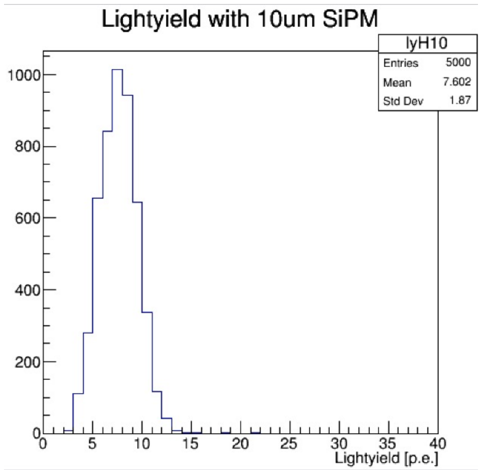
Reconstruction
- reconstruct energy from p.e.
- SSA
- calculate JER by PFA

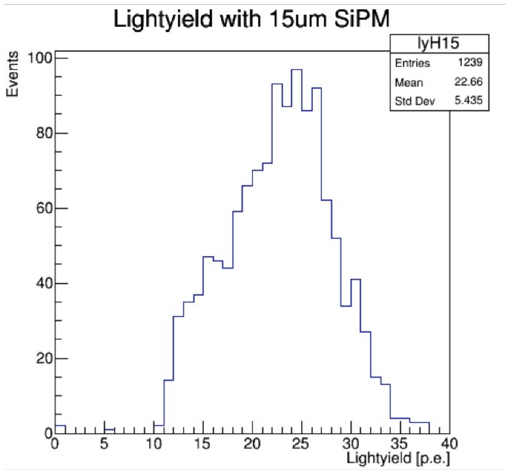
Position dependence of light yield



ILD simulation with realistic effects

- Simulation parameters according to results of large Sc-ECAL prototype test
  ➡ **Np.e. per MIP** and **Npixel** have been changed
  ➡ Dispersion of Npe is also implemented according to following distributions





◀ p.e. distribution obtained from cosmic ray test

- JER & Sc-ECAL resolution are simulated with new saturation models assuming following MPPCs

	pixel size	sensor size	Npixel	Np.e. per MIP
S12571-010P	10 um	1 mm * 1 mm	10,000	7
S12571-015P	15 um	1 mm * 1 mm	4,489	18
S14160-1310PS	10 um	1.3 mm * 1.3 mm	16,675	21
S14160-1315PS	15 um	1.3 mm * 1.3 mm	7,296	38

Effect of SiPM type

Including only new SiPM saturation model

- Linearity for reconstructed MC photon energy

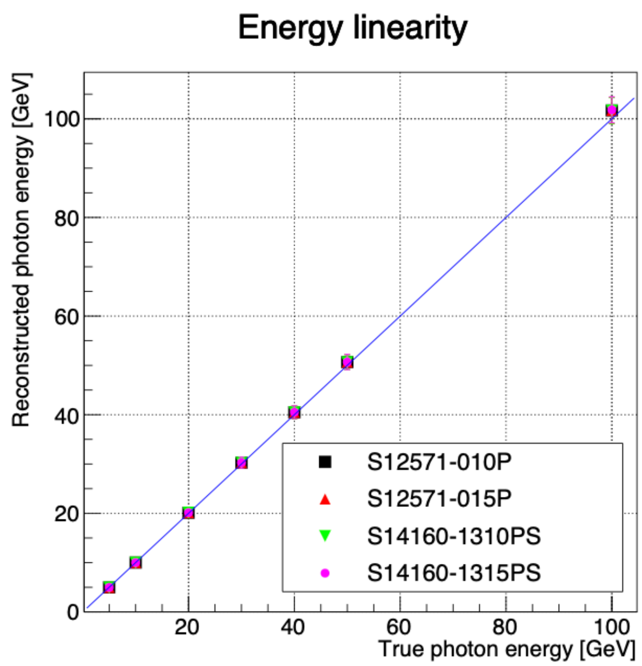
  ➡ Reconstructed photon energy is almost linear with true energy for all models

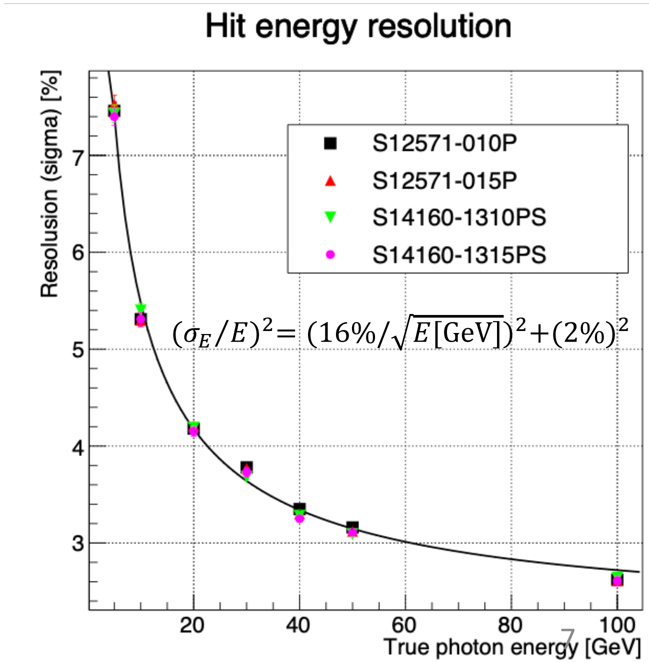
- Energy resolution of Sc-ECAL

  Fit : $(\frac{\sigma_E}{E})^2 = (\frac{a}{\sqrt{E}})^2 + (b)^2$

  ➡ ECAL resolution doesn't depend on SiPM saturation model

- **SiPM saturation does not affect linearity and resolution**





Effect of SiPM type

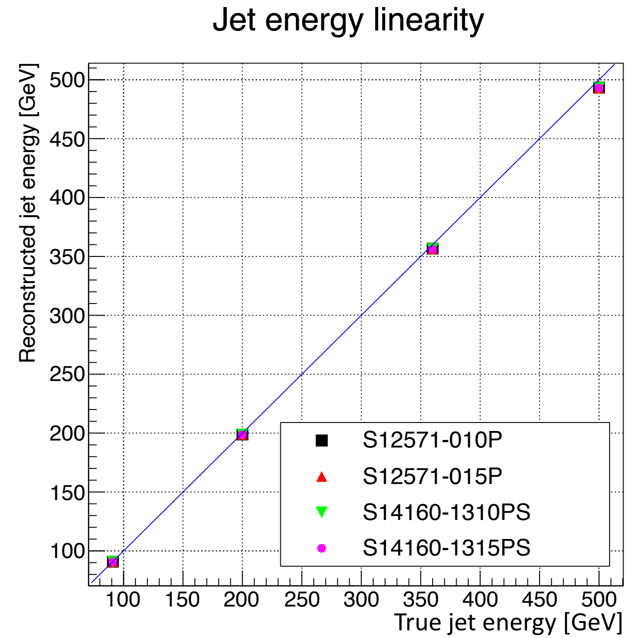
- Reconstructed jet energy is also checked

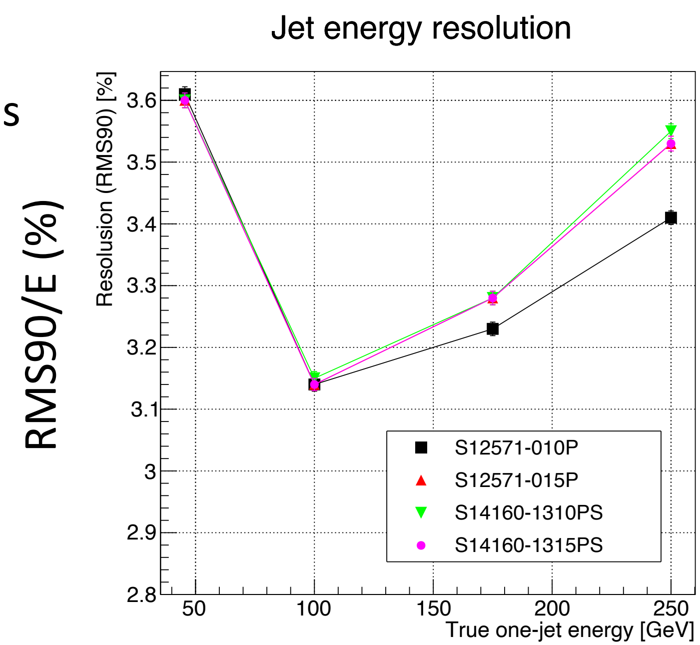
    ➡ Good linearity for all MPPC models

- JER comparison for the 4 MPPC models

    ➡ Use {91, 200, 350, 500} GeV di-jet events
    ➡ There is no big difference between each MPPC model JER

    ➡ S12571-010P has slightly better JER at higher energies
        ➡ Large number of Npixel and small Np.e. per MIP suppress saturation?





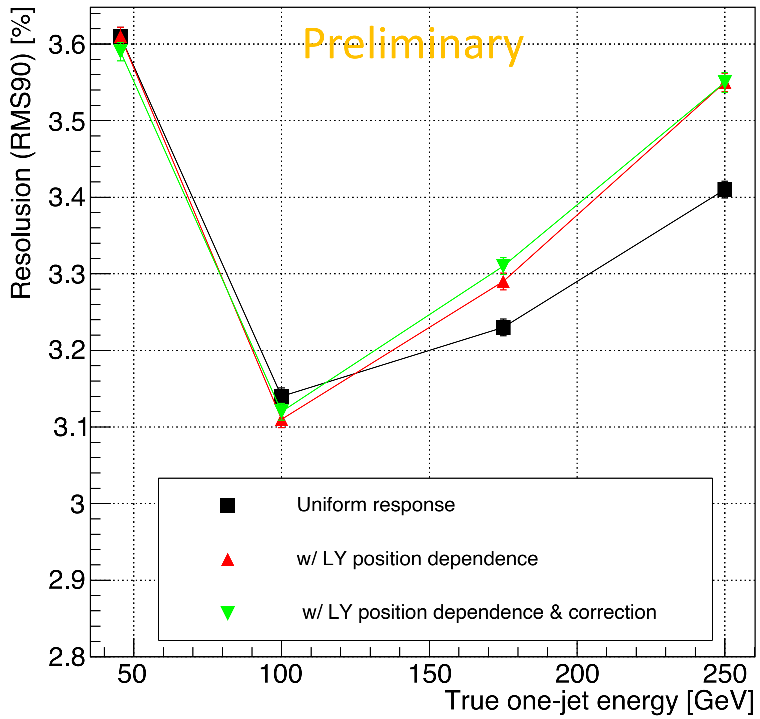
Effect of position dependence of light yield

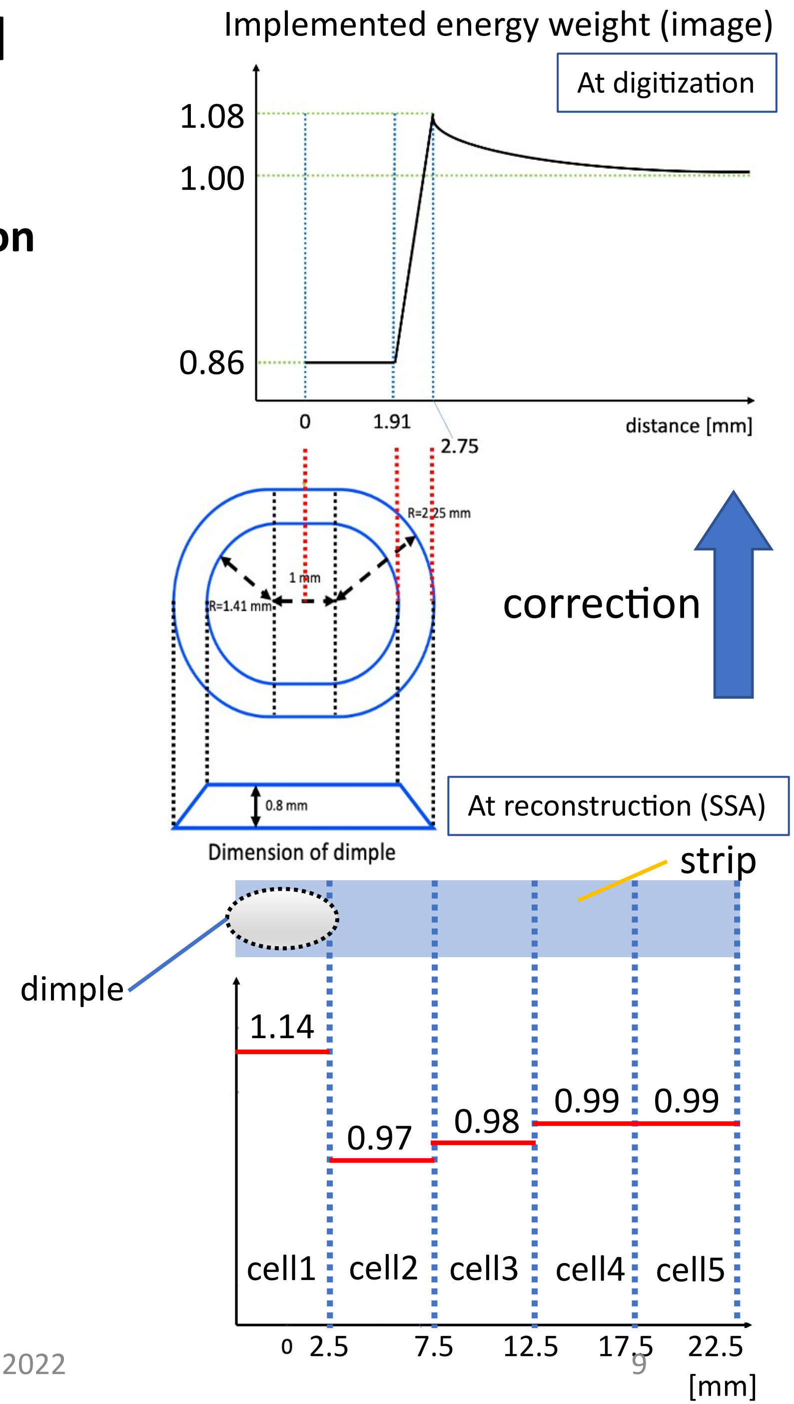
- **Measured position dependence of light yield with S12571-010P**
- **Position dependence is corrected using the hit position reconstructed with SSA**

  ➡ JER is slightly worsened at high energy regions

- Correction with the reconstructed hit position doesn't recover the worsening of the resolution

  ➡ Need better correction method





Summary and Prospects

- ILD simulation study for Sc-ECAL with realistic effects is ongoing

  ➡ New SiPM saturation models was tested (4 MPPC models have been implemented)
    ➡ No big difference, JER is not deteriorated

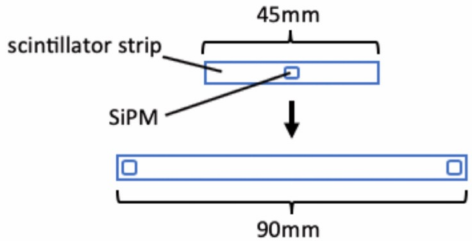
  ➡ Especially for S12571-010P, JER was also tested with hit position dependence of light yield
    ➡ JER is slightly worsened at higher energies
    ➡ The correction according to the reconstructed hit position tried, but without success

- Next Plan

  ➡ More realistic effects to be tested
    ➡ The misalignment/gap between strips
  ➡ Study on the effect of the double SiPM readout on the calorimeter performance

Backup

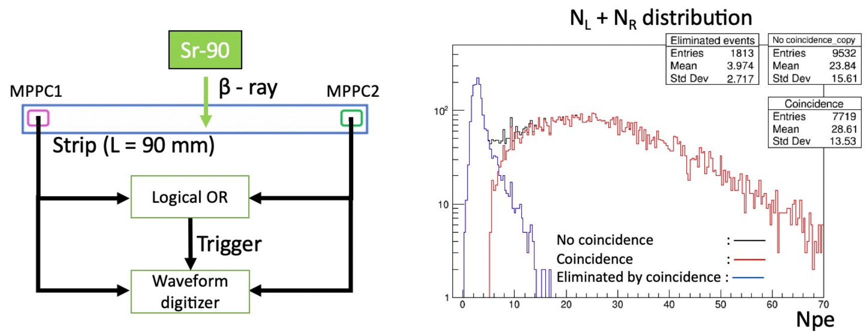
Double SiPM readout



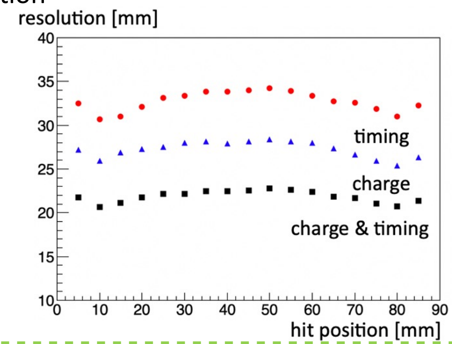
- Possible advantages
  - Eliminating noise by taking coincidence between two SiPM readouts
  - Hit position on a strip can be reconstructed with ~20 mm resolution
    ➡ Possibility of solving ghost hit
  - Higher light yield than single readout by summing two SiPM readouts
- Further studies on performance for double SiPM readout are in progress

Measured performance

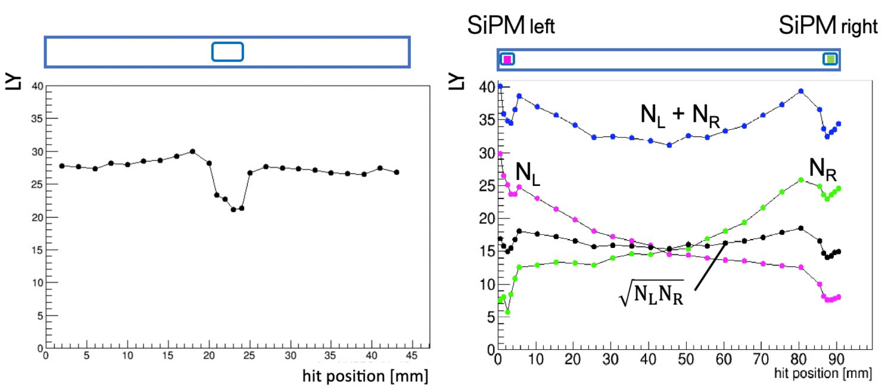
Noise suppression by coincidence



Position resolution



Light yield

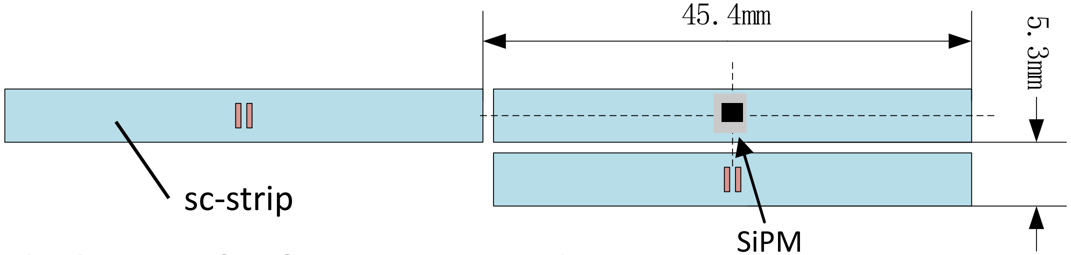


45 mm single readout

90 mm double readout

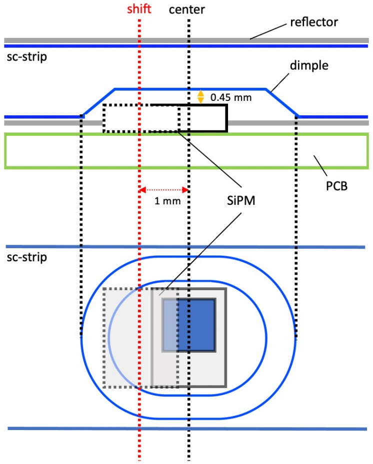
Possible SiPM-strip misalignment on EBU

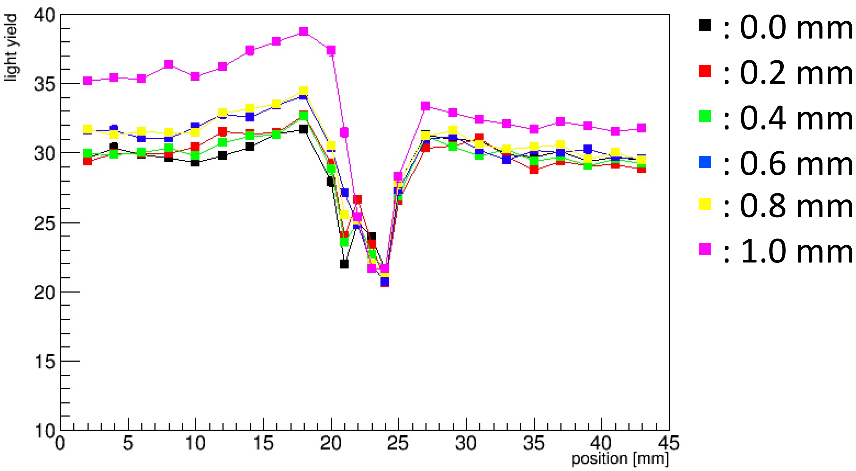
- Layout of strips on readout board (ECAL Base Unit, EBU)



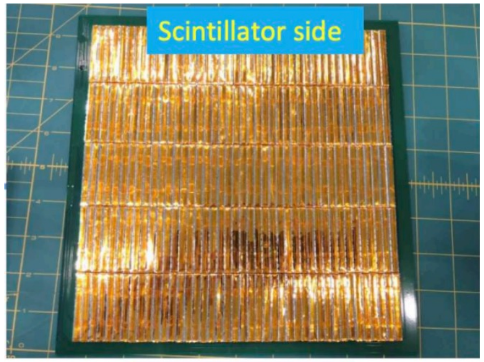
Thickness of reflector : 0.065 * 2 mm
Thickness of Kapton tape : 0.05 * 2 mm

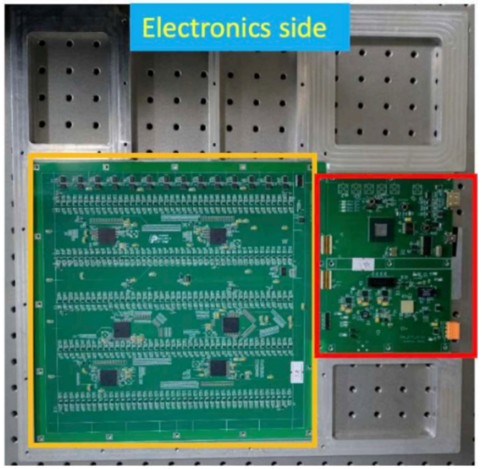
- The effect of strip-SiPM misalignment on the light yield distribution has been investigated by both simulation and measurement



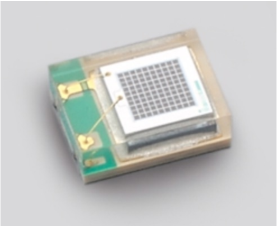


- Uniformity of light yield is affected only when the misalignment is as large as 1 mm





ECAL Base Unit (EBU)



MPPC : S12571-015P
(1 x 1 mm^2 15μm-pixel)
hit position[mm]

Gap correction at ILD simulation

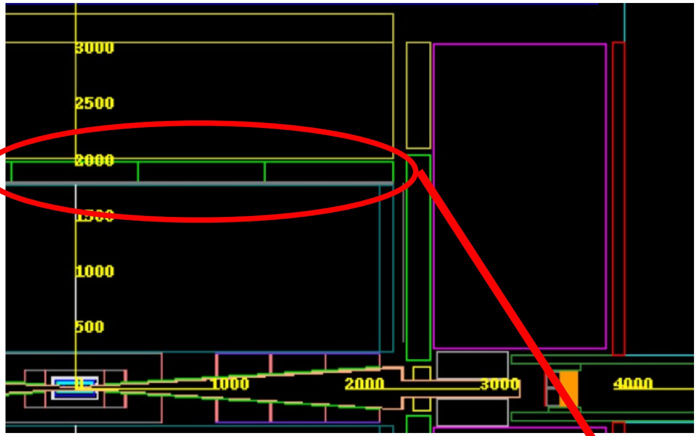
Correction of gap effect on ECAL

- Correction of the gap effect on ScECAL

  ➡ ECAL barrel consists 5 ECAL modules
  ➡ ECAL modules consists 5 EBU slabs

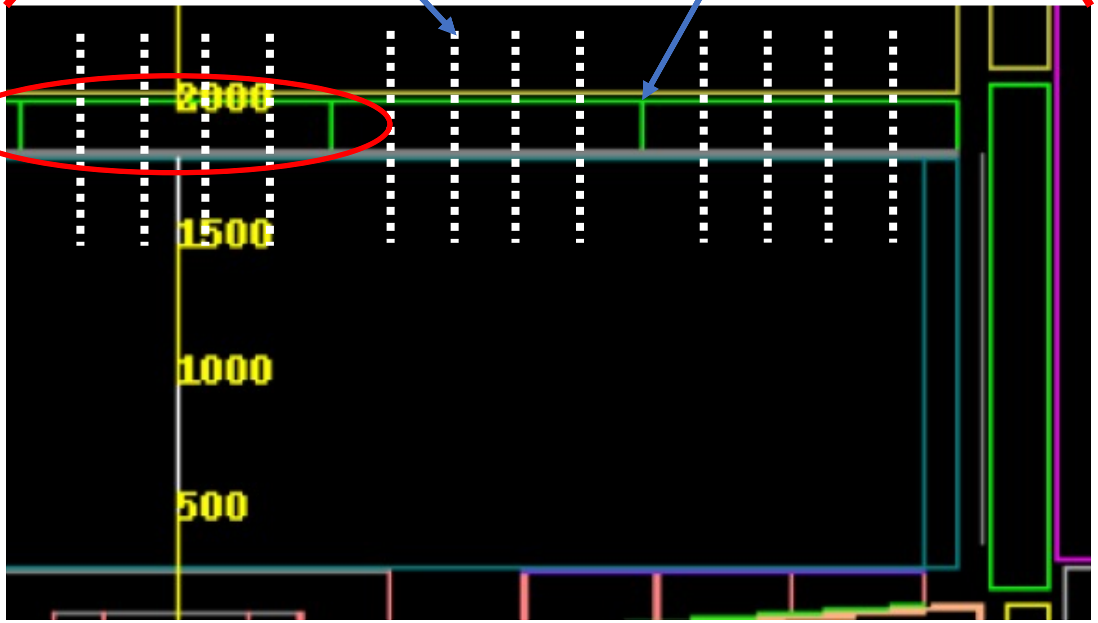
- There are 4 gaps between modules and 20 gaps between slabs in barrel area along beam direction

ECAL

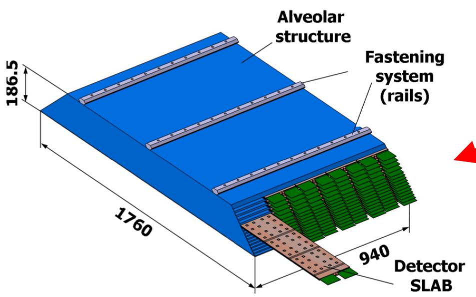


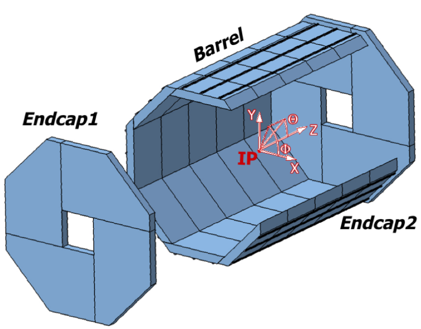
Gap between slabs 0.1 mm

Gap between modules 0.2 mm



Beam axis



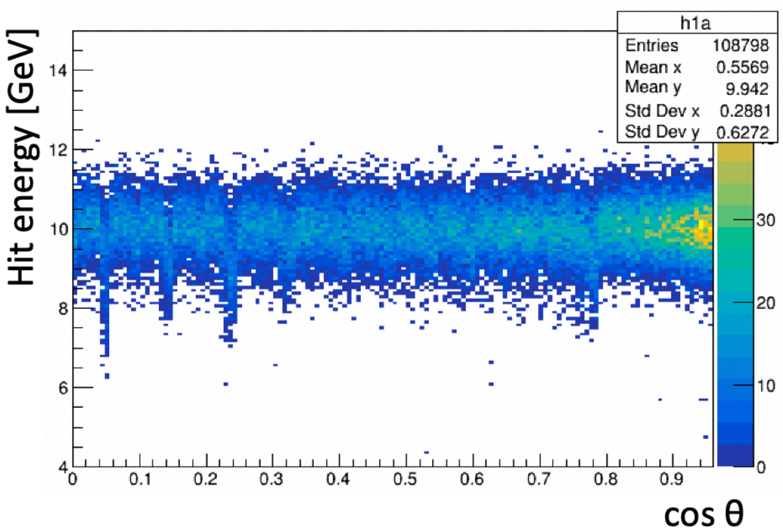


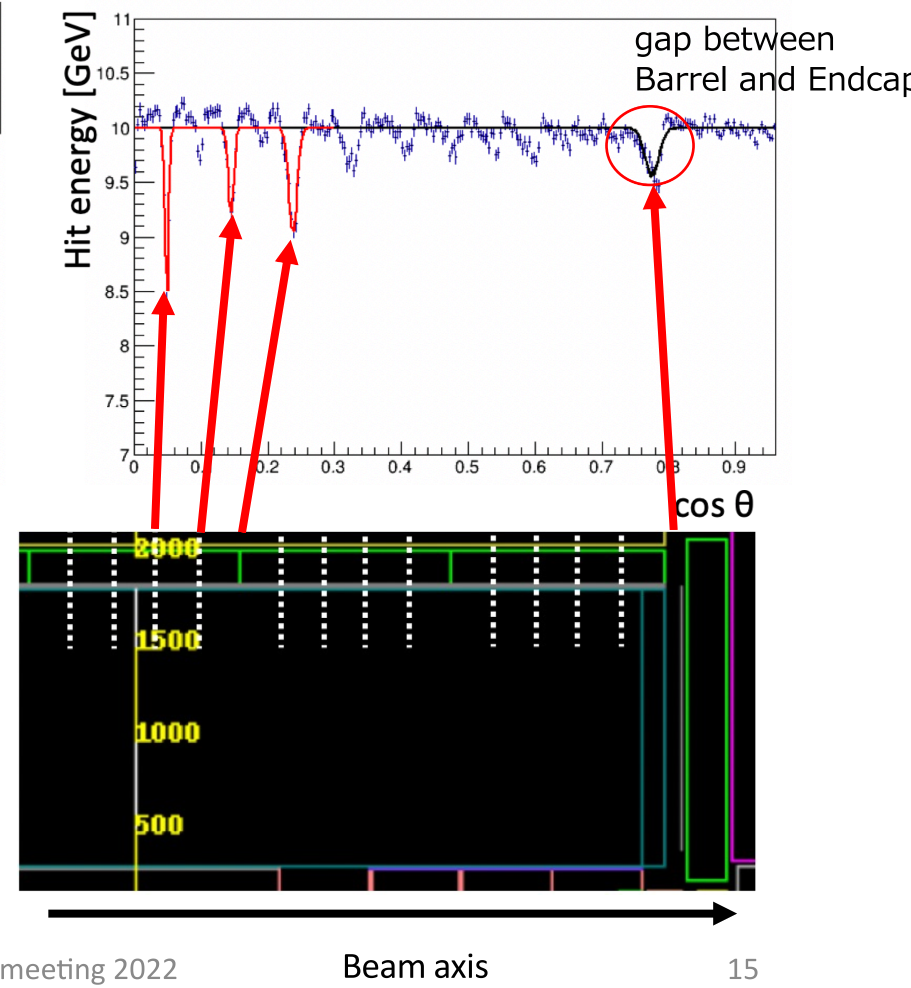
Gap correction at ILD simulation

Correction of gap effect on ECAL

- Angular distribution of simulated hit energy along beam direction

➡ Deficit of reconstructed energy around the gaps between ECAL modules





- **First 3 deficits (red line) + barrel & endcap boundary (black line) are corrected**

$$E_{mod} = \frac{E_{true}}{E_{true} - E_{fit}} \times E_{hit}$$

E_{true} : true energy (10 GeV)

E_{fit} : Energy deficit obtained by fitting

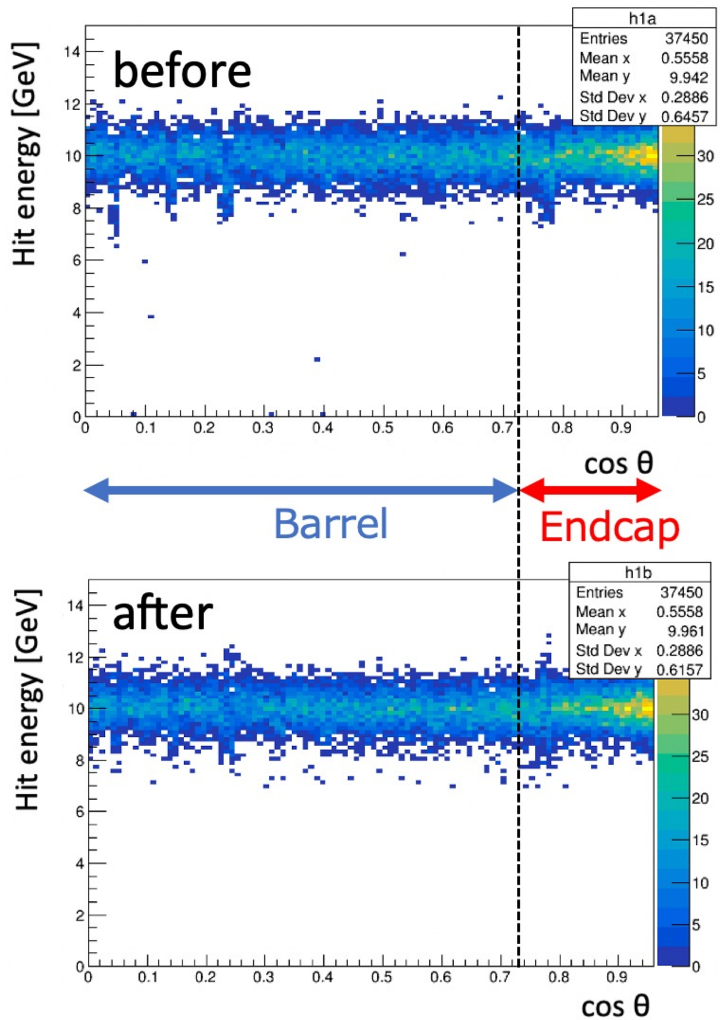
Gap correction at ILD simulation

Correction of gap effect on ECAL

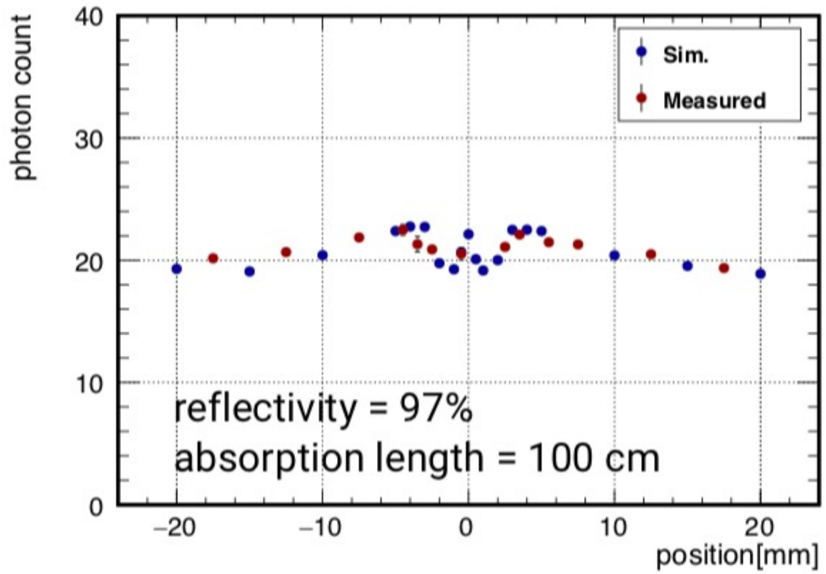
- Angular distribution of simulated hit energy along beam direction

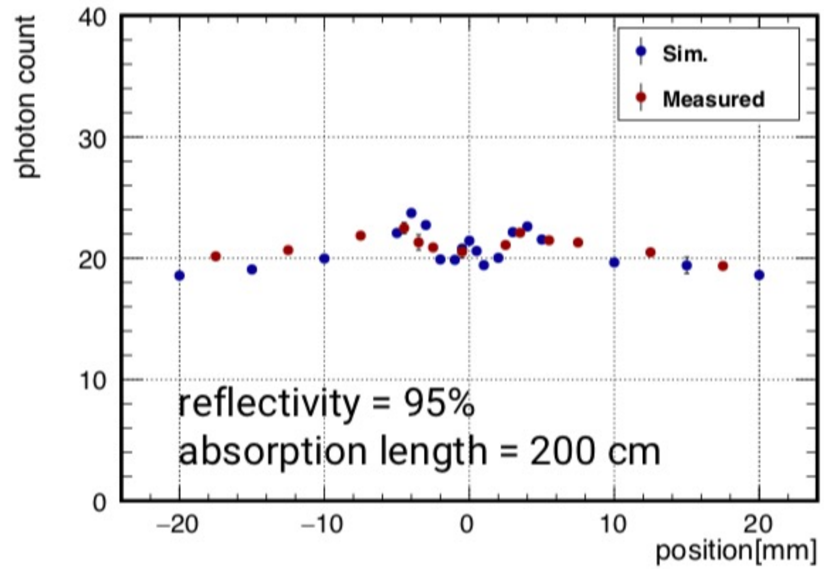
  ➡ Deficit of reconstructed energy around the gaps between ECAL modules

- **The nonuniformity has been mitigated to some extent**



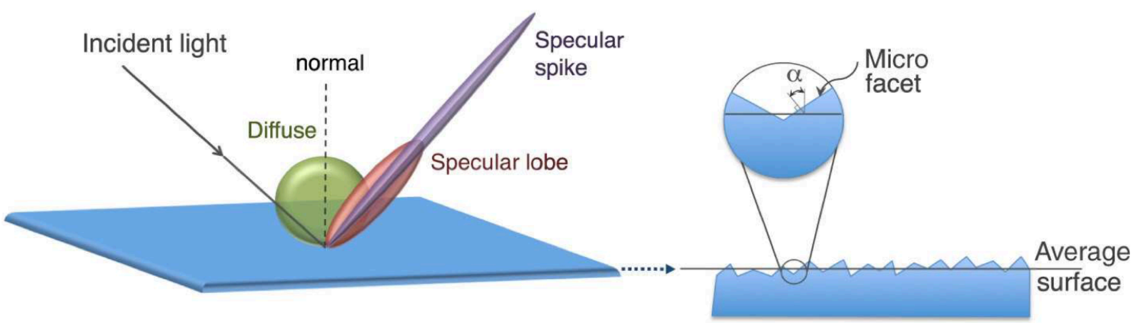
Optimization of parameters for Geant4 Optical Photon simulation





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

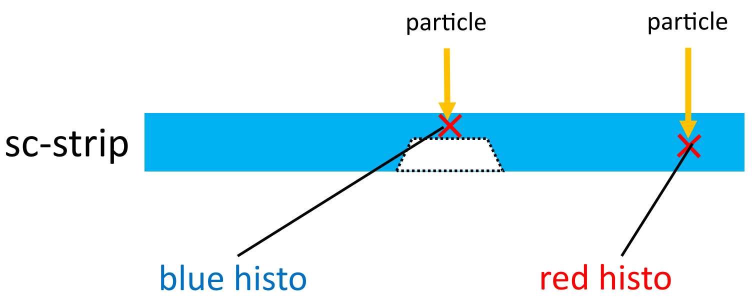
パラメータ名	設定値
Specular Spike	0
Specular Lobe	0.9
Diffuse Lobe	0.1
Back Scattering	0
発生光量 (photons/1 MeV e^-)	1,800
屈折率	1.58
吸収長 (cm)	250
反射率	0.98
表面粗さ (rad)	0.1



Hit energy scaling in ILD simulation

Verification of scaling the energy deposit in strip

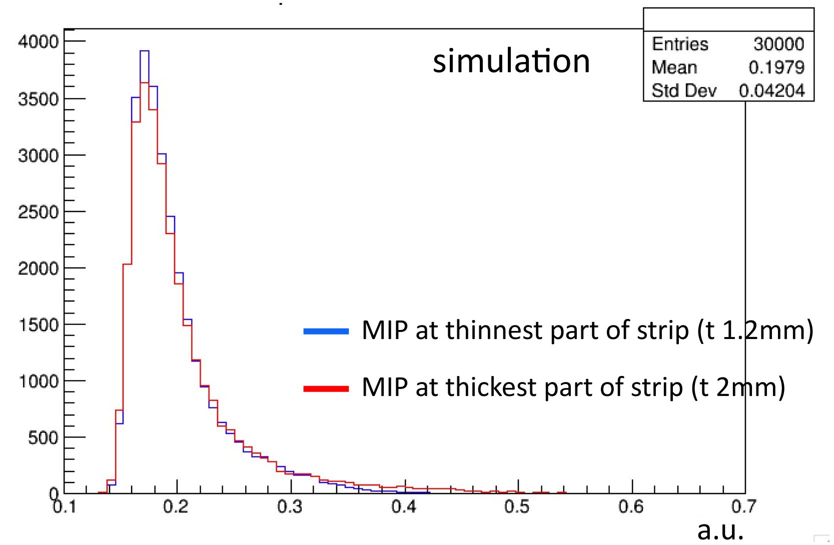
- Found that the shape of the energy deposit distribution doesn't depend on the energy deposit (simulation)



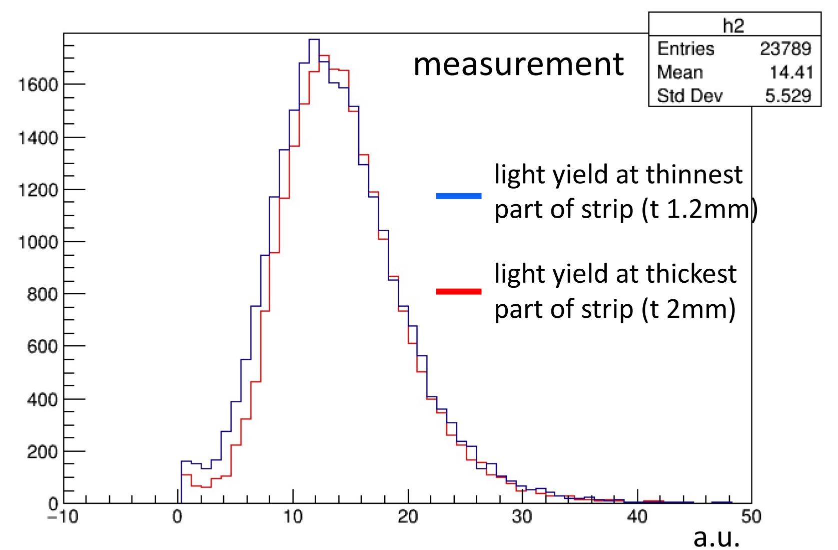
- The same for the light yield (measurement)

➡ The effect of the position dependence of the strip response can be included in simulation **by scaling the energy deposit based on the observed position dependence of the light yield**

Energy deposit distribution (normalized with peak position)



Light yield distribution (normalized with peak position)

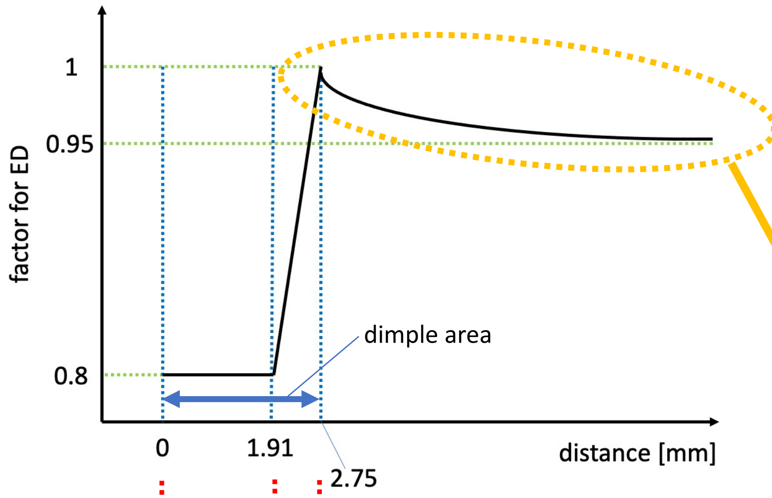


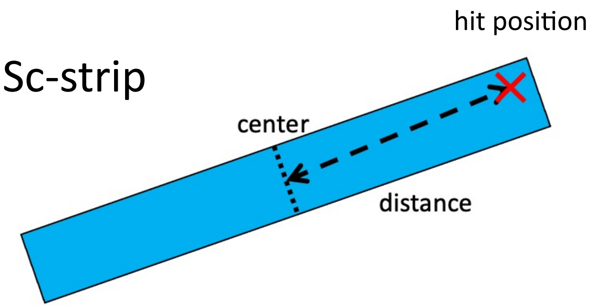
ILD simulation study

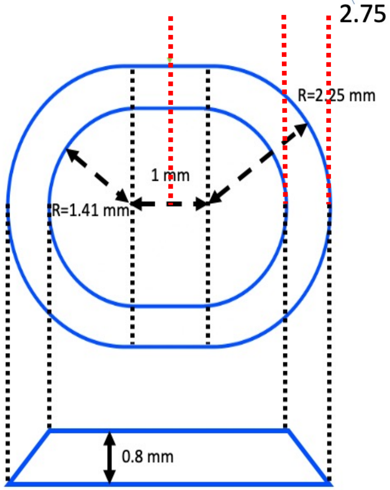
Implementation of position dependence of light yield

- Implemented weight factor for energy deposit

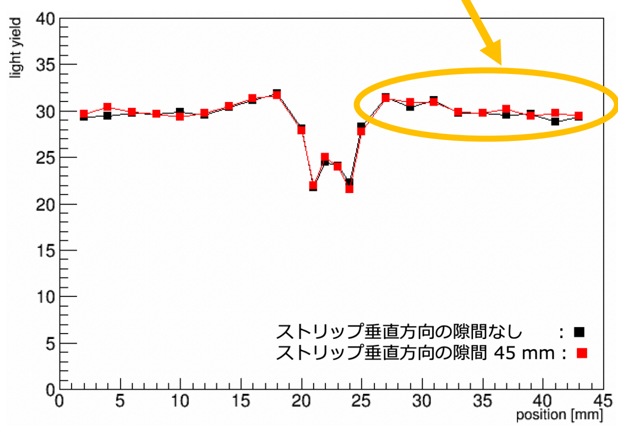
(distance)
= (distance between center of strip
and hit position)

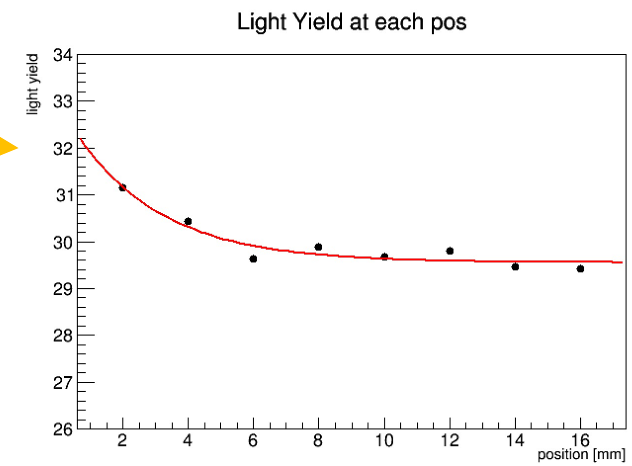






Dimension of dimple





➡ Using fitting function of simulated (normalized) light yield distribution

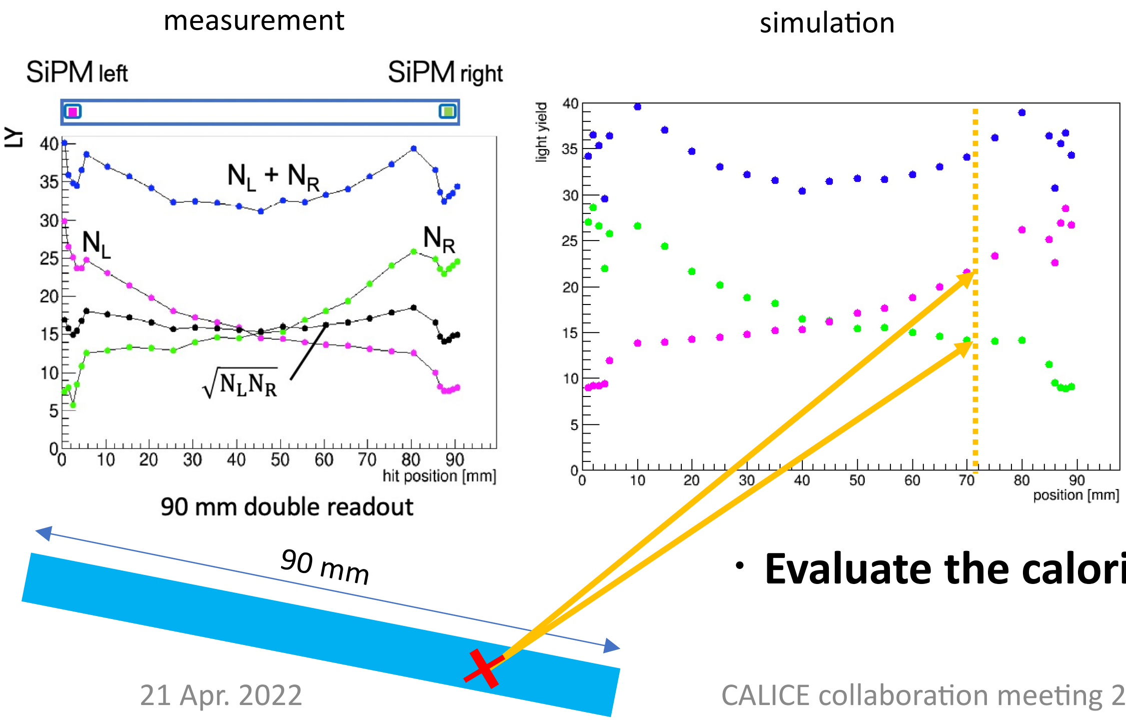
Plan in future

Plan to implement the double SiPM readout (DR)

The effect of double SiPM readout on calorimeter performance will be studied.

- Eliminating noise by taking coincidence between two SiPM improve detection efficiency by lowering the threshold (currently at 0.5MIP)

- Hit position on a strip can be reconstructed
  ➡ Possibility of mitigating ghost hit
- Higher light yield than single readout by summing two SiPM readouts



- **Evaluate the calorimeter performance based on DR data**

ILD simulation with real SiPM saturation model

- SiPM saturation model

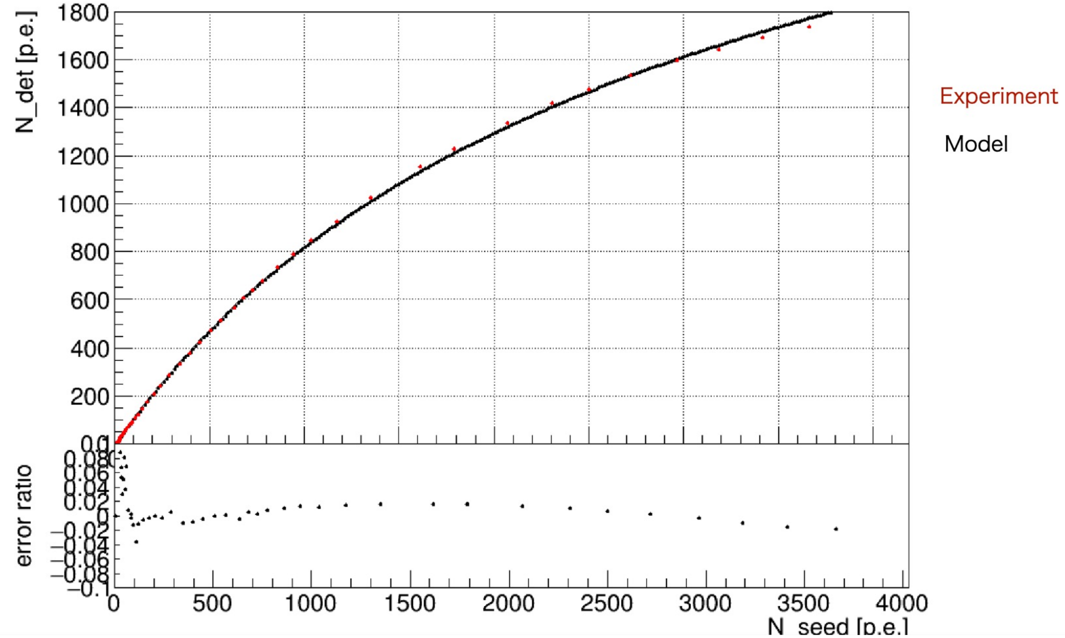
  ➡ Default function

$$N_{det} = N_{px} * \left(1 - e^{-N_{pe}/N_{px}}\right)$$

  Npx : Number of pixels = 10,000

  ➡ This model can not reproduce real behavior of SiPM saturation

Implemented model



- Implemented new function

  ➡ Including time constant of scintillator (EJ-212), SiPM recovery time, CTAP effect

- Investigating JER with this saturation model assuming to use 4 specific MPPCs