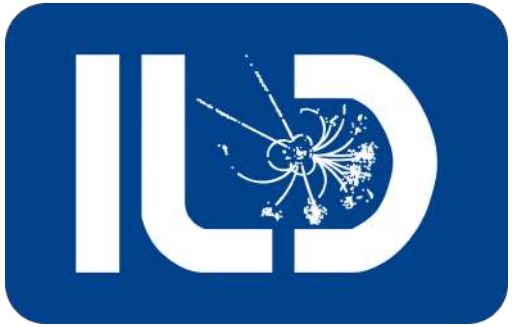


Development of double SiPM readout method for ILD scintillator electro-magnetic calorimeter

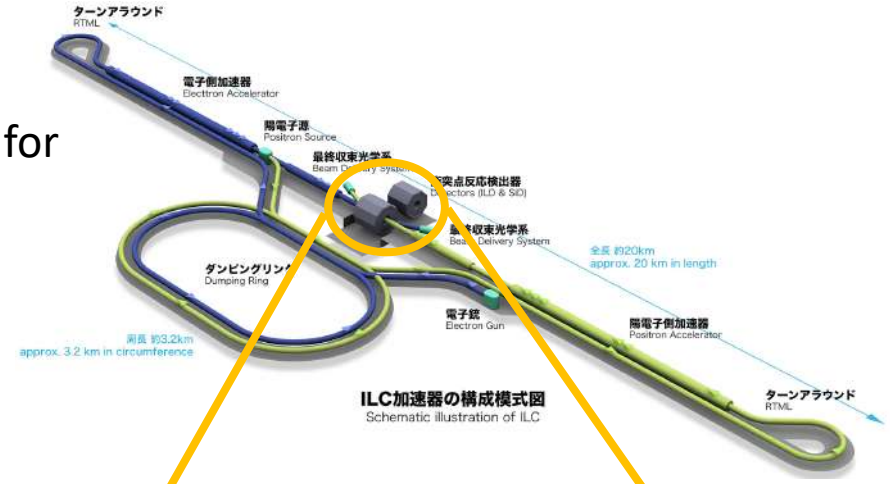
Ryunosuke Masuda, The University of Tokyo
Linghui Liu, Naoki Tsuji, Wataru Ootani
CHEF at Fukuoka, 26 Nov. 2019

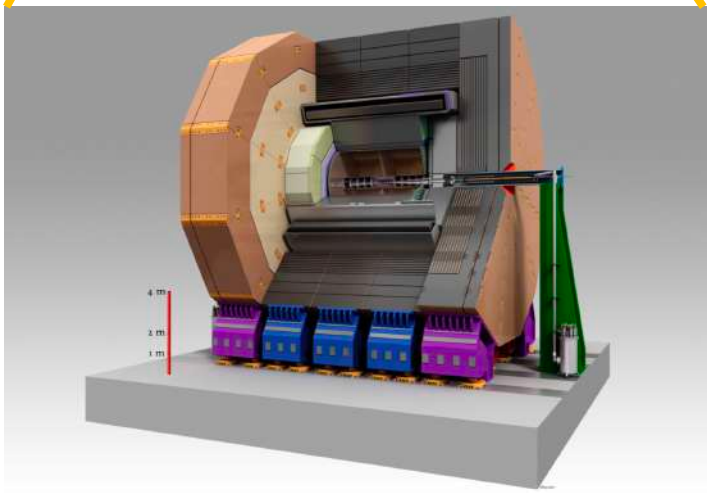
ILD at ILC

- ILC is a future linear electron-positron collider for precise measurement of Higgs boson

  ➡ CM energy : 250GeV

  ➡ Can be upgraded to higher energy by extending the length





- ILD : One of the two detector concepts proposed for ILC

  ➡ All the detectors (tracking system, calorimeter) have high precision optimized for particle flow calorimetry

ECAL at ILD

- Technological options for ECAL

Si-ECAL (5 x 5 mm^2 silicon pad)

➡ Excellent S/N of silicon sensor

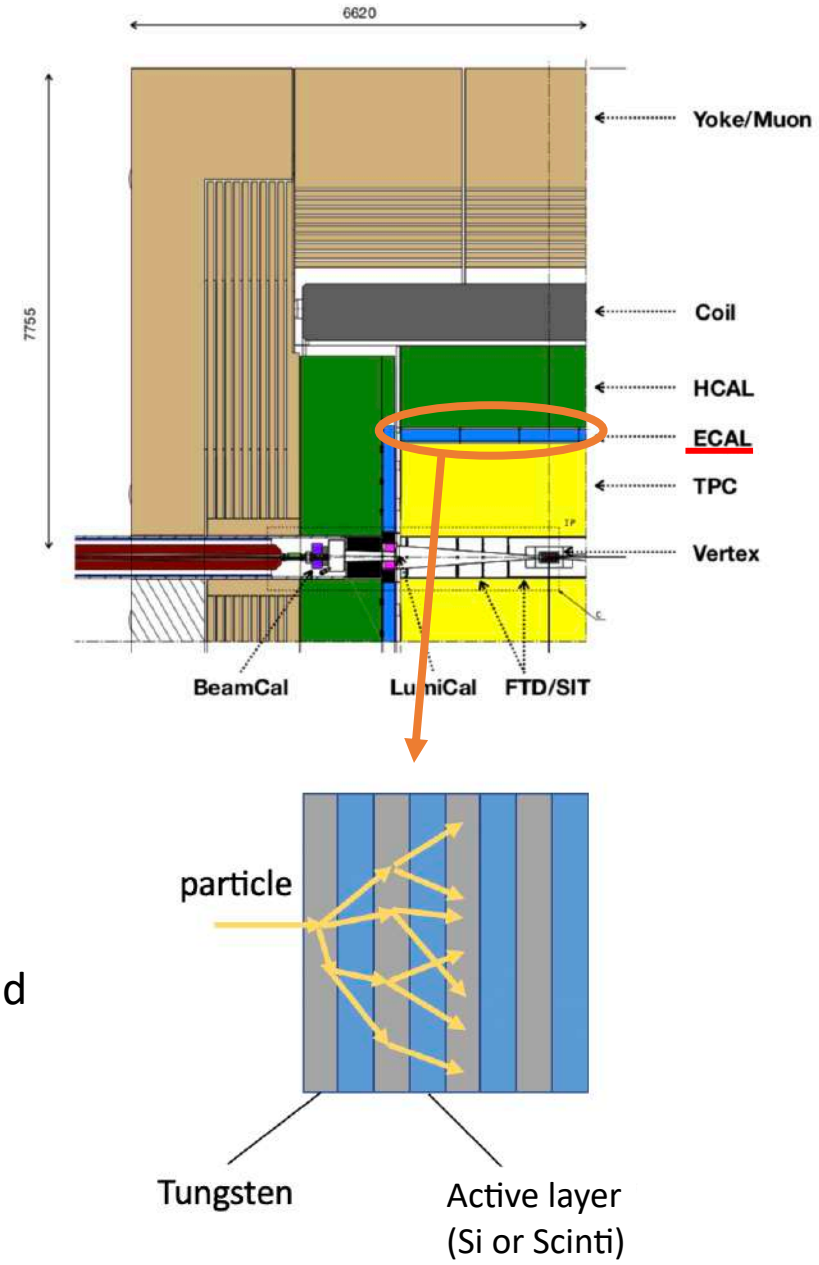
➡ Expensive

Sc-ECAL (5 x 45 mm^2 scintillator strip)

➡ Moderate S/N of scintillator strip

➡ Ten times smaller # of readout channels with comparable calorimeter performance

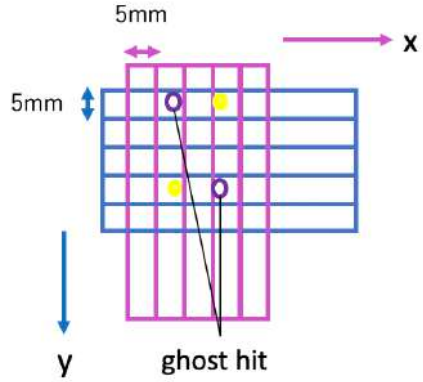
- Aim of this study : To develop a new readout method for scintillator strip of Sc-ECAL



Sc-ECAL

- A design concept for ECAL based on strip-shaped plastic scintillator
- Virtual 5 × 5 mm^2 cell segmentation by strip x-y configuration

Ghost hit : From two or more simultaneous hits



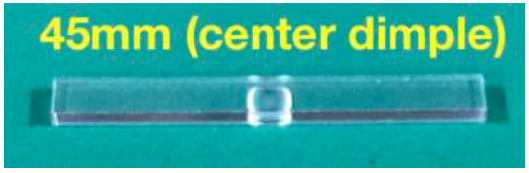
- Possible solution

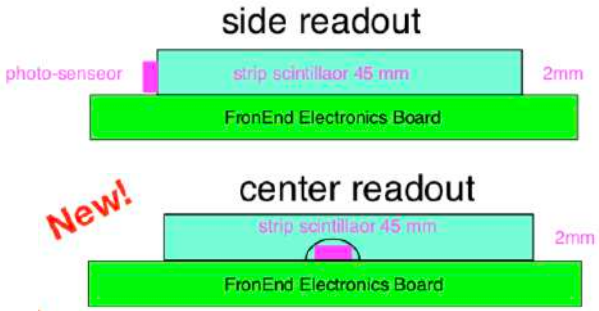
  ➡ Interleaving square scintillator tile (a la AHCAL) to solve ambiguity

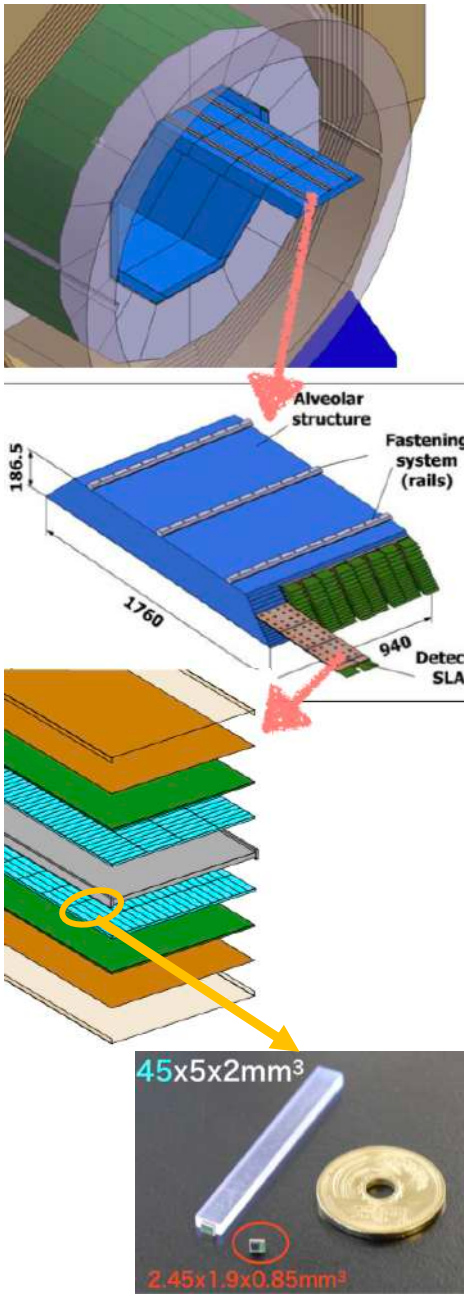
  ➡ Position reconstruction by double SiPM readout (to be discussed later)

- A strip with SiPM in a dimple (a la AHCAL) has been proposed by Chinese group

  ➡ Suitable for large scale production







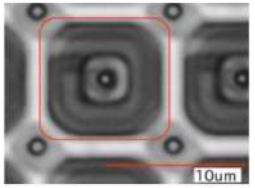
Sc-ECAL

・Need SiPM with small pixel (= large N_{pixel}) for wide dynamic range

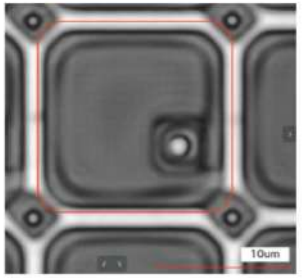
➡ MPPC with 10-15μm pixel developed by Hamamatsu

Model Number	S12571-010P	S12571-015P
Photosensitive area	1mm²	1mm²
Pixel size	10μm	15μm
Number of pixels	10000	4489
PDE	10%	25%
Gain	1.35x10⁵	2.3x10⁵
Geometrical fill factor	33%	53%

10μm pitch

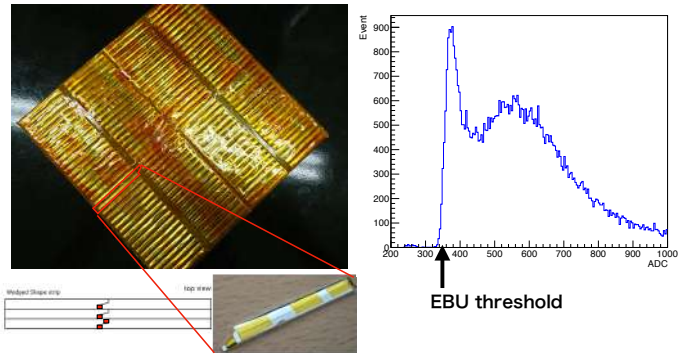


15μm pitch



➡ 15μm with higher gain and PDE would be a better choice from S/N viewpoint

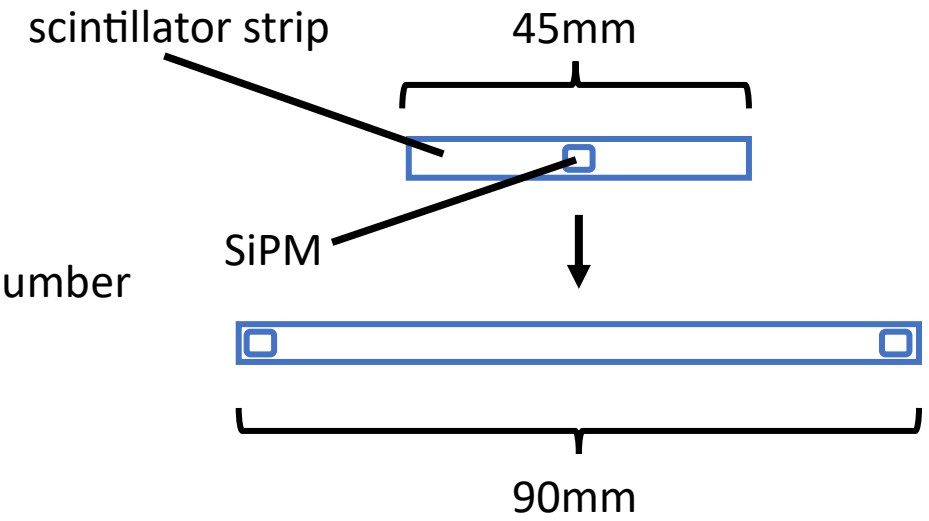
➡ However, still may not be enough even with 15μm



Test beam experiment with 15μm pixel MPPC by Shinshu Univ.

We are developing a new SiPM readout method to improve performance of scintillator strip

Double SiPM readout



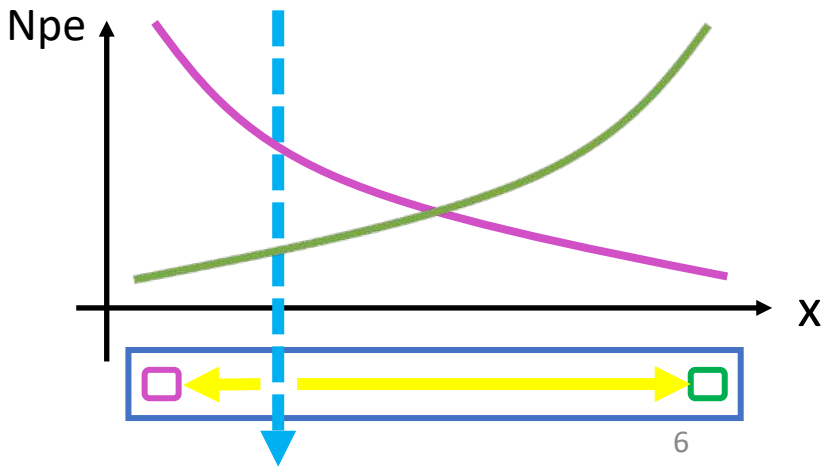
- **Readout by two SiPMs at strip ends**

  ➡ Twice longer strip (L=90mm) to keep the number of SiPMs

- Possible advantages

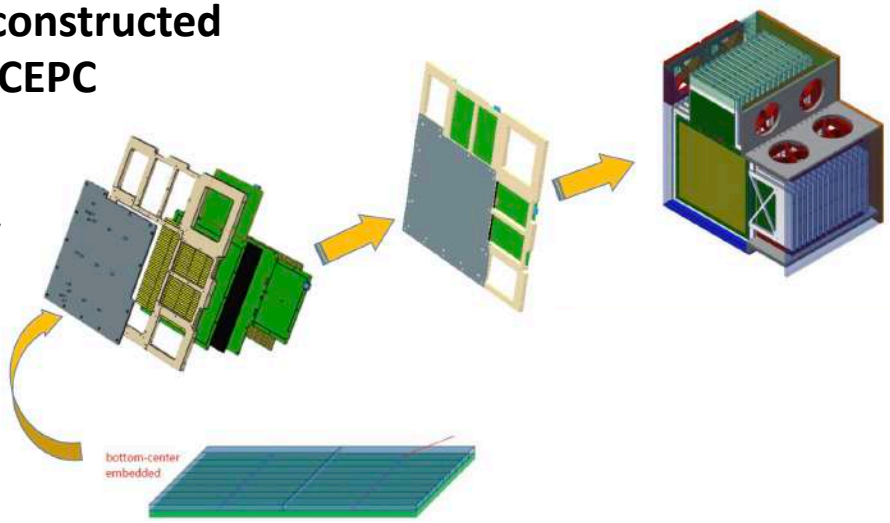
  - **Eliminating noise by coincidence**
    ➡ even better S/N
  - Higher light yield by summing two SiPM readouts
  - Even lower light yield for each SiPM
    (➡ less saturation)
  - Still operational even if one of SiPMs is dead

- Position reconstruction by charge or timing difference between two readouts
  ➡ Challenging



Double SiPM readout for Sc-ECAL prototype

- **Large technological prototype for Sc-ECAL to be constructed as a joint effort with Chinese groups working on CEPC**
  - ➡Full 30 layers
  - ➡To be constructed and tested in beam by end of next year

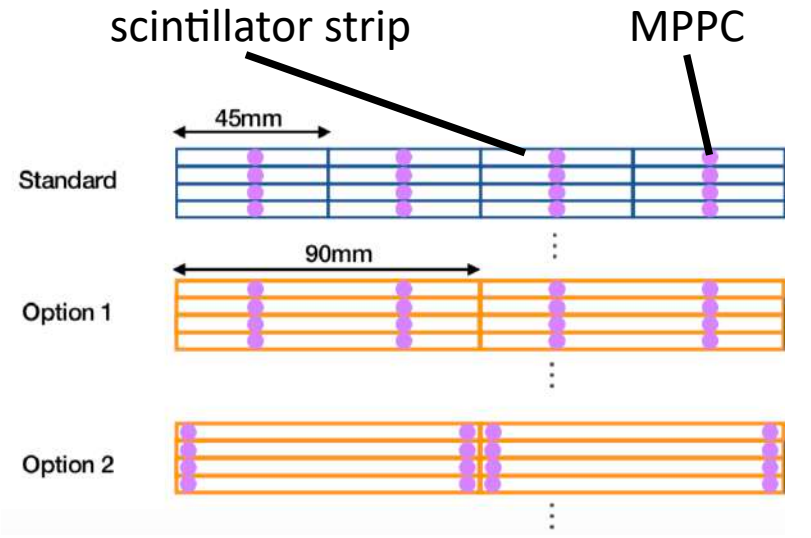


- **Planning to add a few detection layers with double SiPM readout to Sc-ECAL prototype**

- Two possibilities of implementation

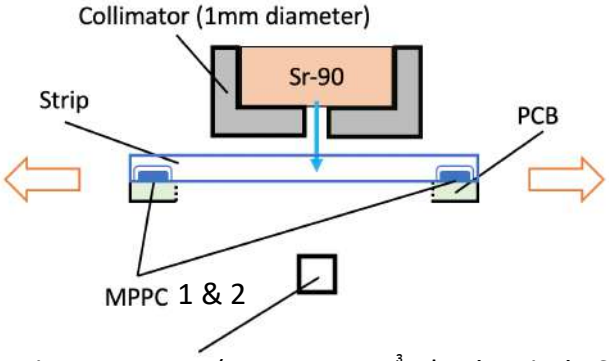
Option 1
- Two SiPMs in the middle of the strip
- SiPM positions compatible with standard readout PCB

Option 2
- Two SiPMs at the strip ends
- Need to modify SiPM positions on readout PCB

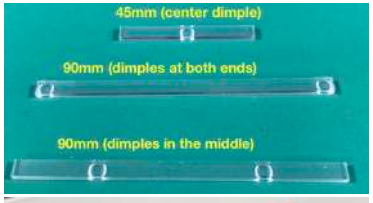


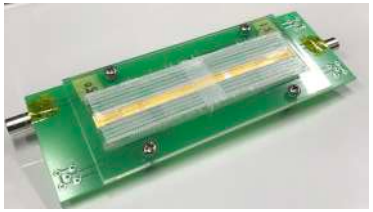
- **Prototype tests for double readout for two options were performed**

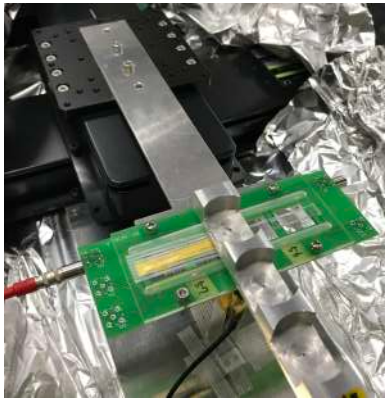
Setup



Trigger counter (5×5×5 mm³ plastic scinti.+SiPM)





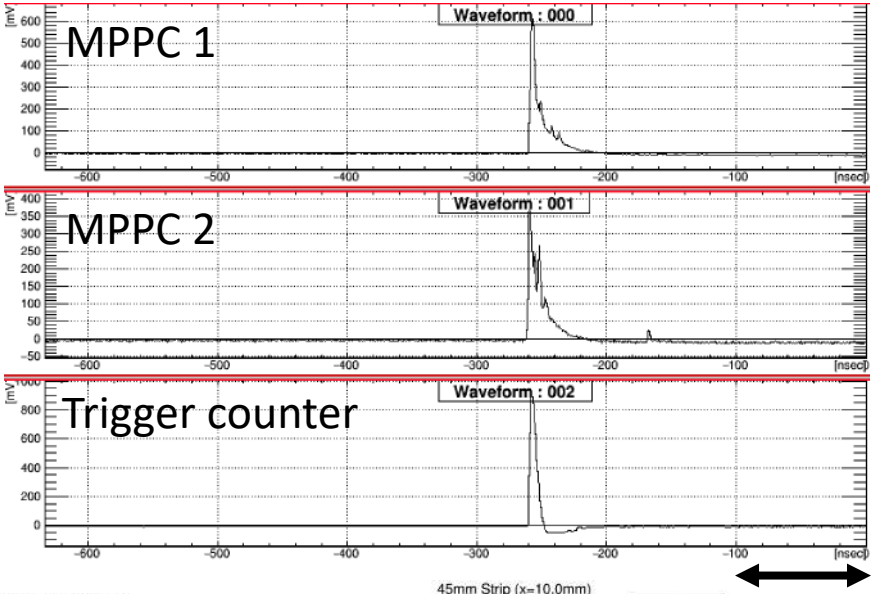


Plastic scintillator：EJ-212　　Reflector：ESR2 (laser-cut)

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

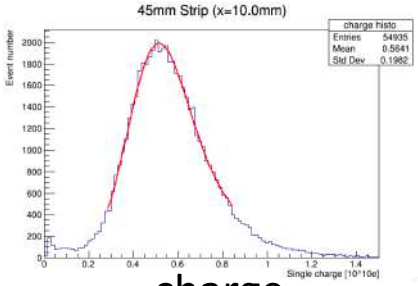
V_{op} : ~ 68V

Waveform digitizer

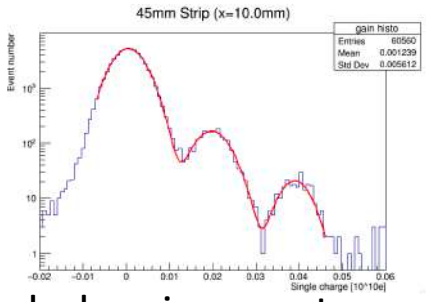


100 ns

- Measurement
  - Position dependence of N_{pe} for 2 types of 90mm strip
  - 45mm strip with center dimple was also tested for comparison



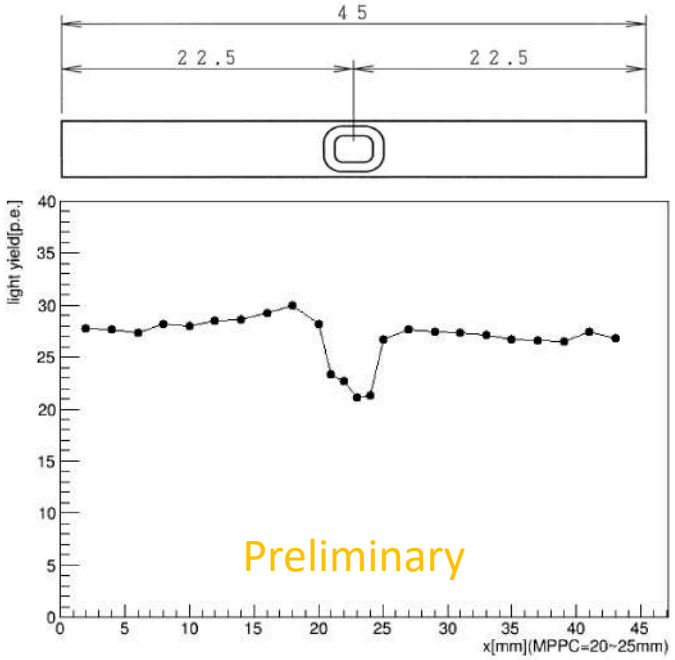
charge



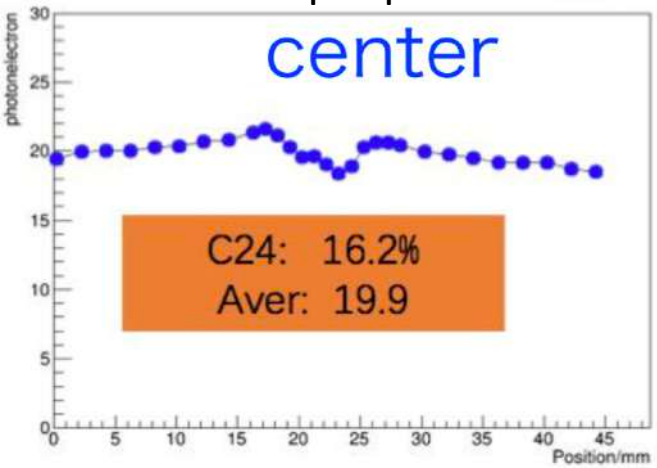
dark noise spectrum

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

Results : 45mm strip with single readout

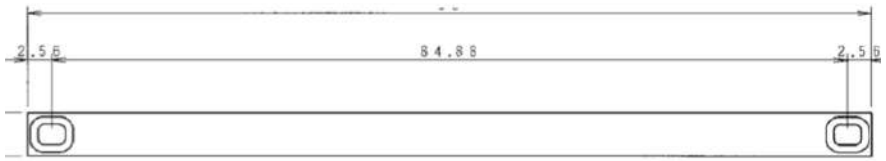


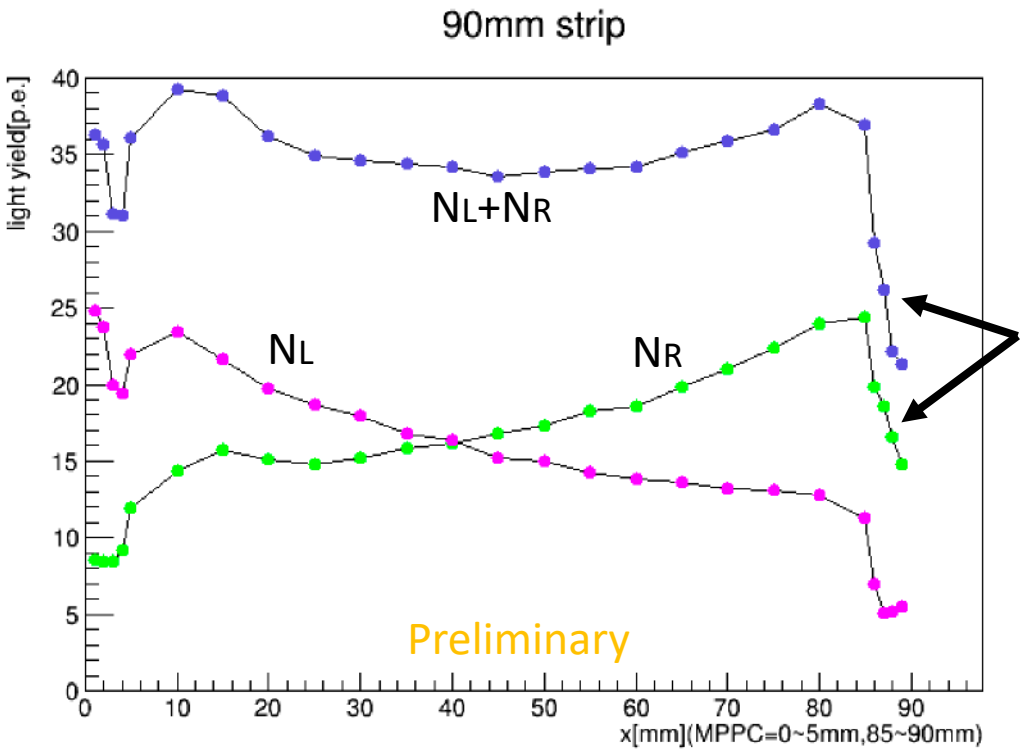
Measured by Chinese group
MPPC with 10µm pixel was used



- Just to check consistency with previous study
- Npe ~ 27 (average)
- Larger than observed by Chinese group
  - ➡ Higher PDE for 15µm than 10µm MPPC used for Chinese setup
  - ➡ Lower over-voltage (~5V) compared to 7V for Chinese setup
- Larger reduction of light yield around dimple
  - ➡ Misalignment (shift of sensor from center of dimple) can be considered

Results : 90mm strip with double readout at strip end





More or less flat response with sum of two readouts

Npe ~ 35 (average)

- Larger than 45mm strip
- Even lower for each MPPC

➡ less saturation

Strange behavior at right end

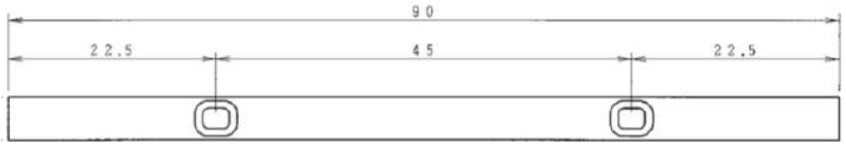
- Misalignment?
- Under investigation

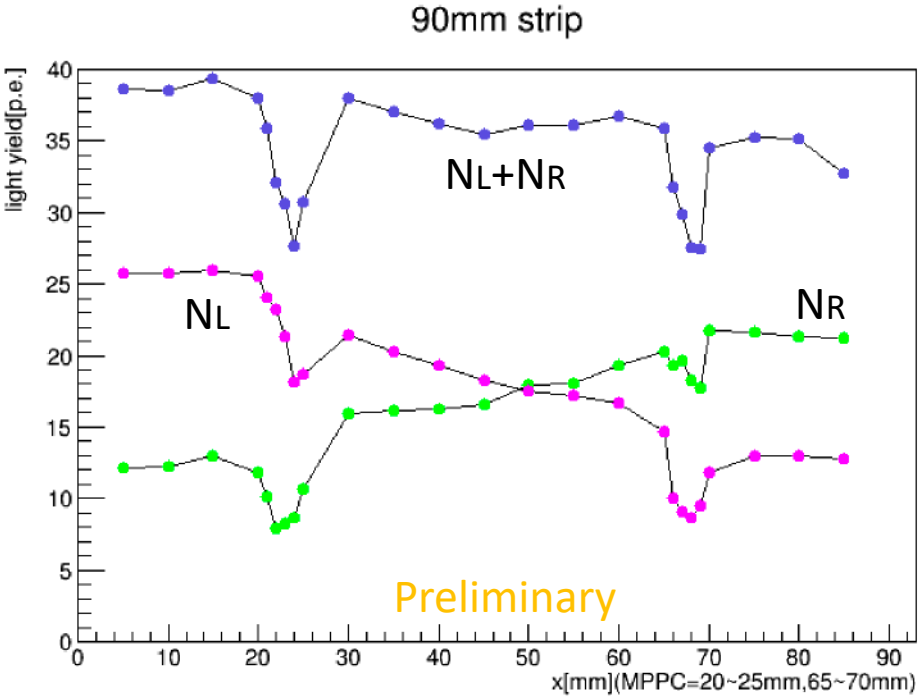
Position-dependent Npe for each MPPC readout

- Possibility of position reconstruction using charge or timing

➡ To be discussed later

Results : 90mm strip with double readout in middle of strip





More or less flat response with sum of two readouts

Npe ~ 35 (average)

- Larger than 45mm strip
- Even lower for each MPPC

➡ less saturation

Response curve is slightly slanted

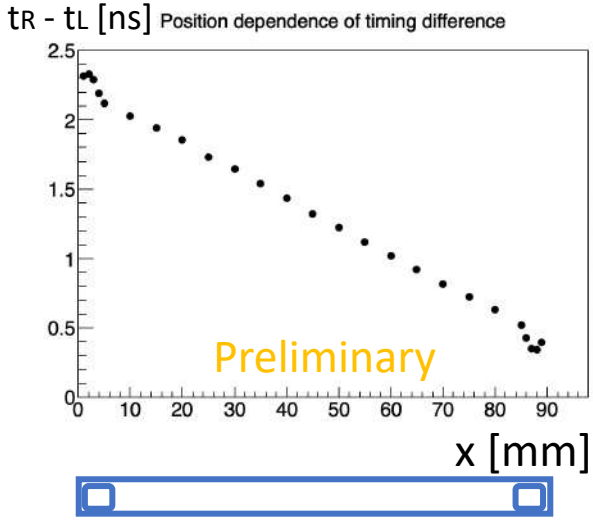
➡ Misalignment?

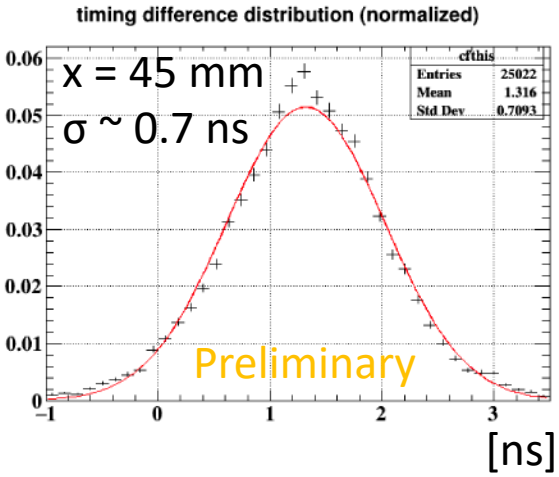
No position dependence outside dimples

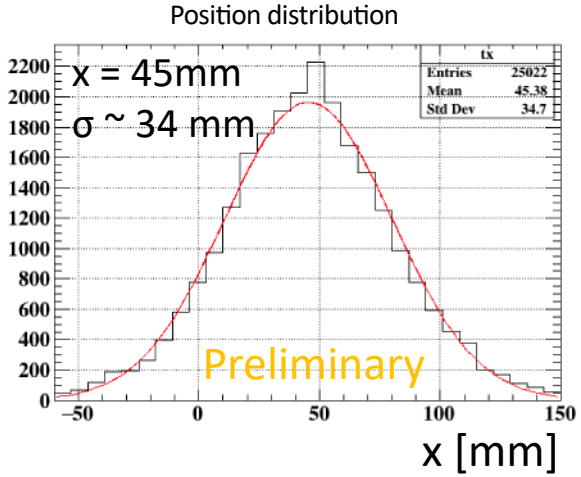
➡ No chance of position reconstruction outside dimples at least by charge difference

➡ N.B. this is a tentative configuration only for prototype

Results : position reconstruction from timing difference



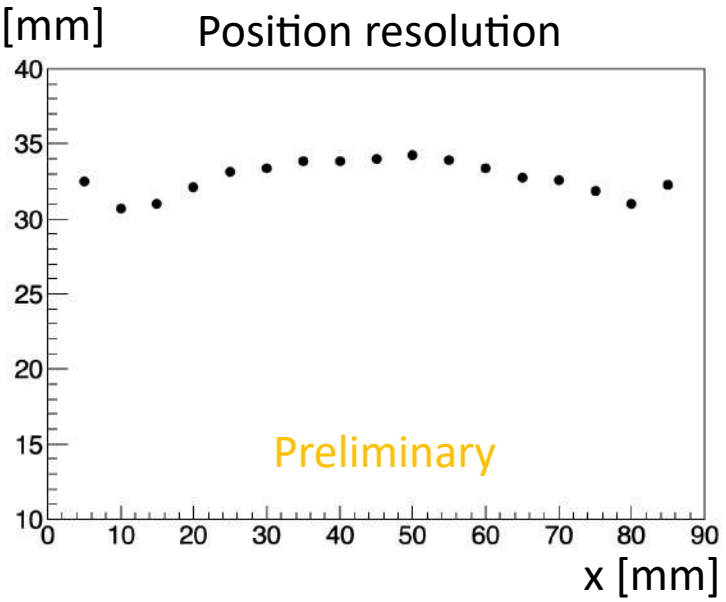




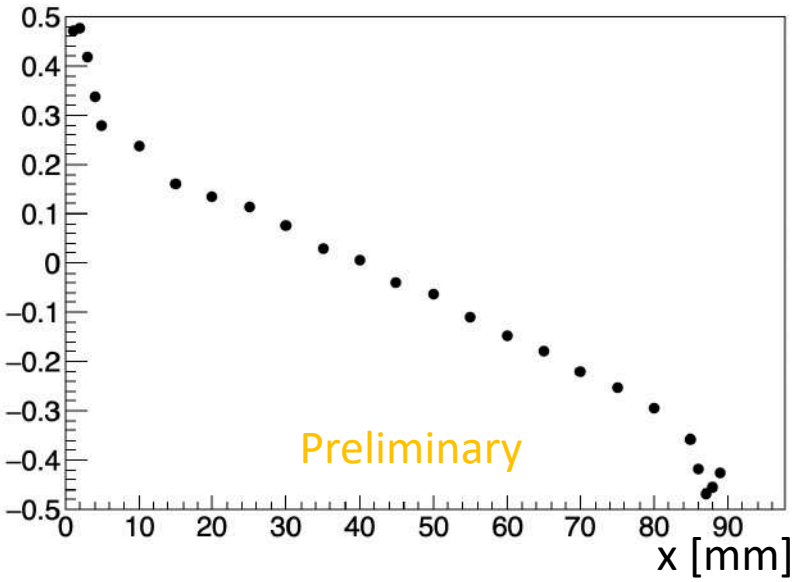
- Dimples at both ends

- Position reconstruction by timing difference
  - ➡ **σ ~ 32 mm** was obtained with preliminary setup (for x = 5 ~ 85 mm)

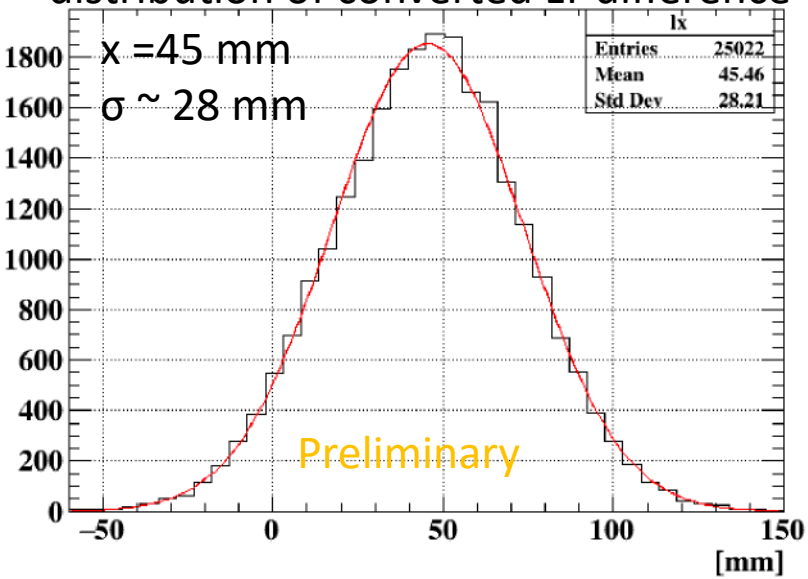
- This lab. study was performed with high-speed waveform digitizer, but it's not possible in the detector.
  - ➡ Need to improve timing performance of readout electronics



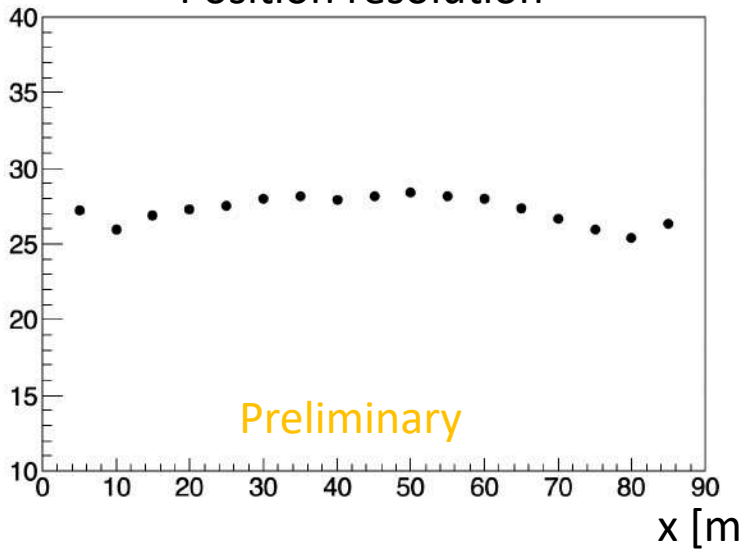
Results : position reconstruction from charge difference



distribution of converted LY difference



σ [mm] Position resolution



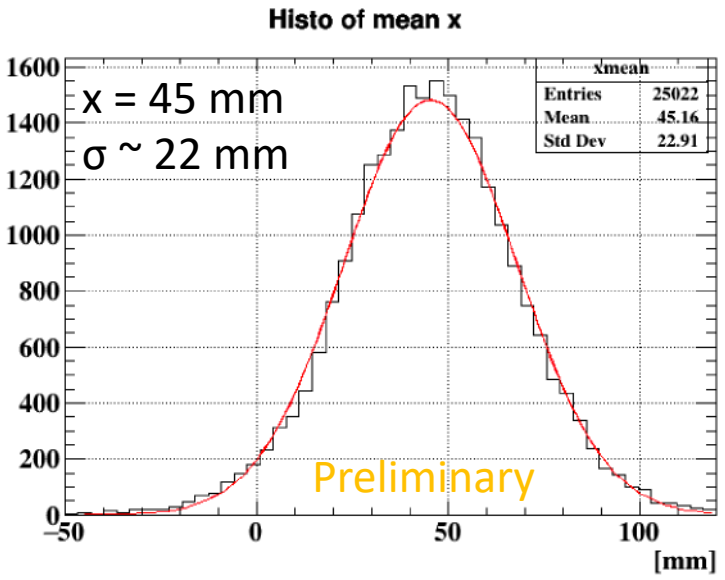
- vertical axis : $\dfrac{LY(L) - LY(R)}{LY(L) + LY(R)}$

- **σ ~ 27 mm** was obtained (x = 5 ~ 85 mm)

Results : position reconstruction

- Position reconstruction from weighted mean of charge and timing difference

$$x_{mean} = \frac{{\sigma_l}^2 x_t + {\sigma_t}^2 x_l}{{\sigma_t}^2 + {\sigma_l}^2}$$

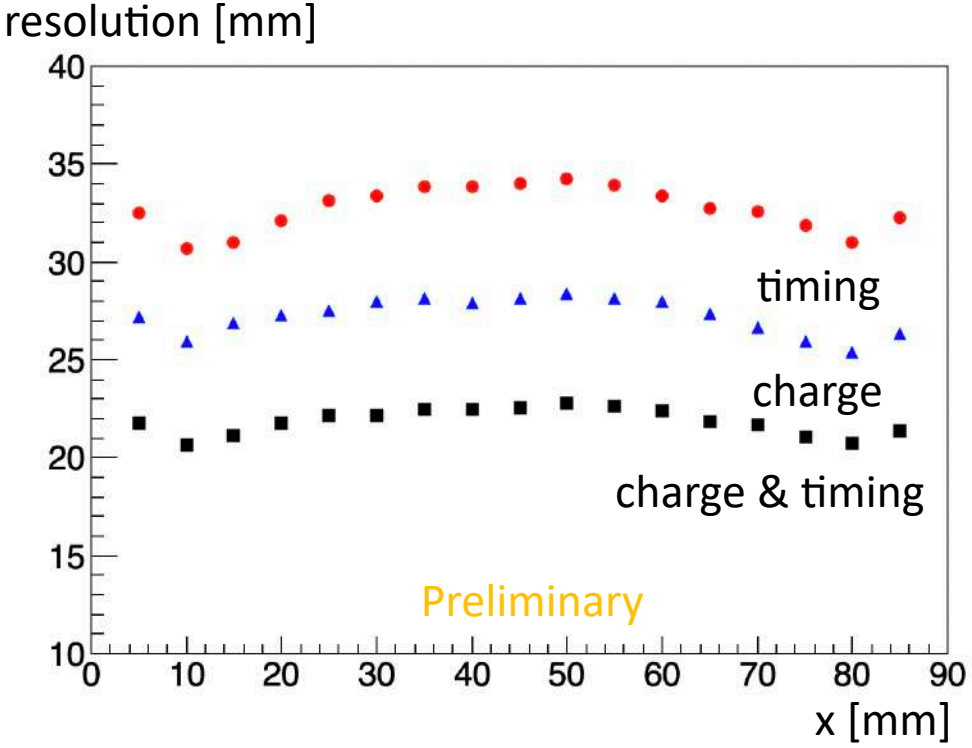


- **σ ~ 22 mm** was obtained

➡ Better than the result from only charge or timing difference

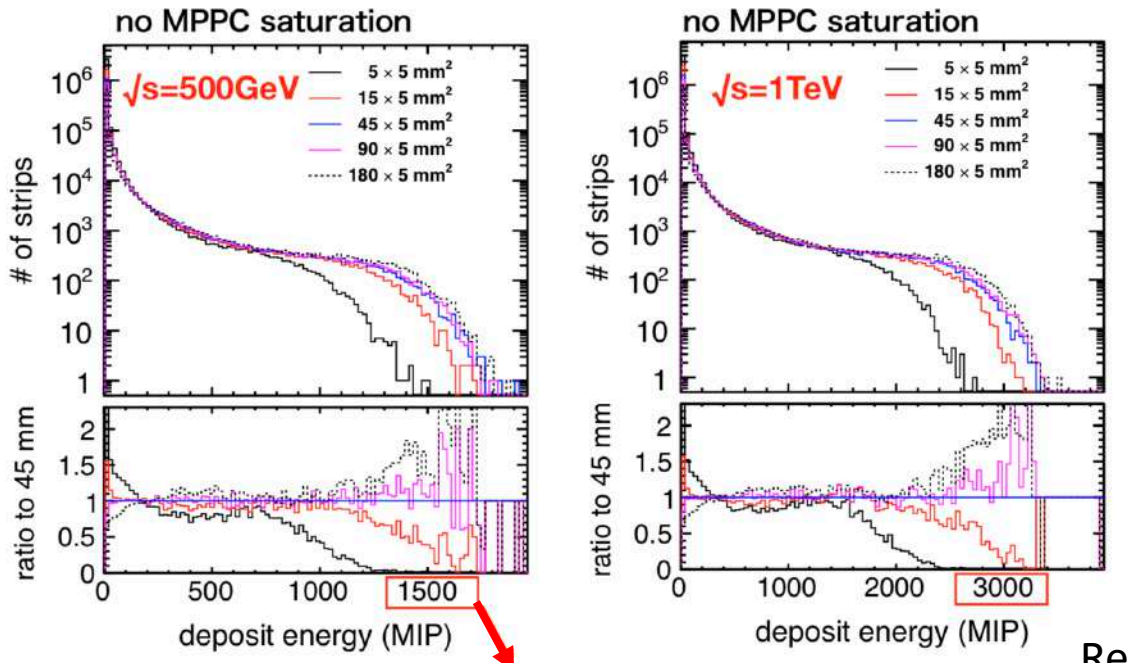
➡ The achieved resolution is not too bad

➡ The effect in calorimeter performance to be studied by MC simulation

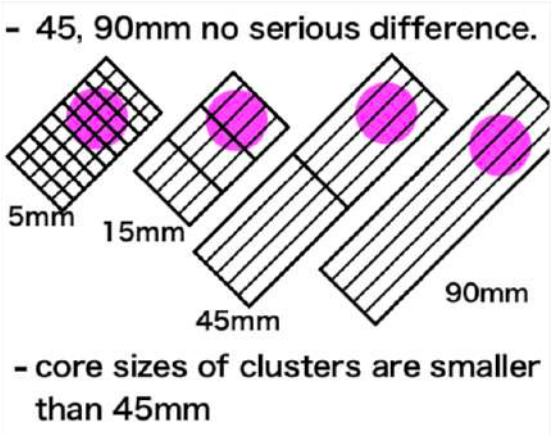


SiPM Saturation with Longer Strip

- Preliminary MC study done by Shinshu group
  ➡ Considering Bhabha events at √s = 500 GeV & 1 TeV

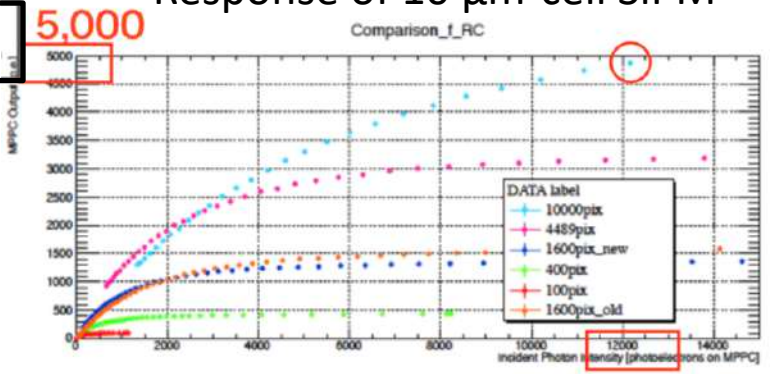


K.Kotera



- 1500MIP ➡ N_{pe} ~ 10k for nominal strip config.

Response of 10 μm-cell SiPM

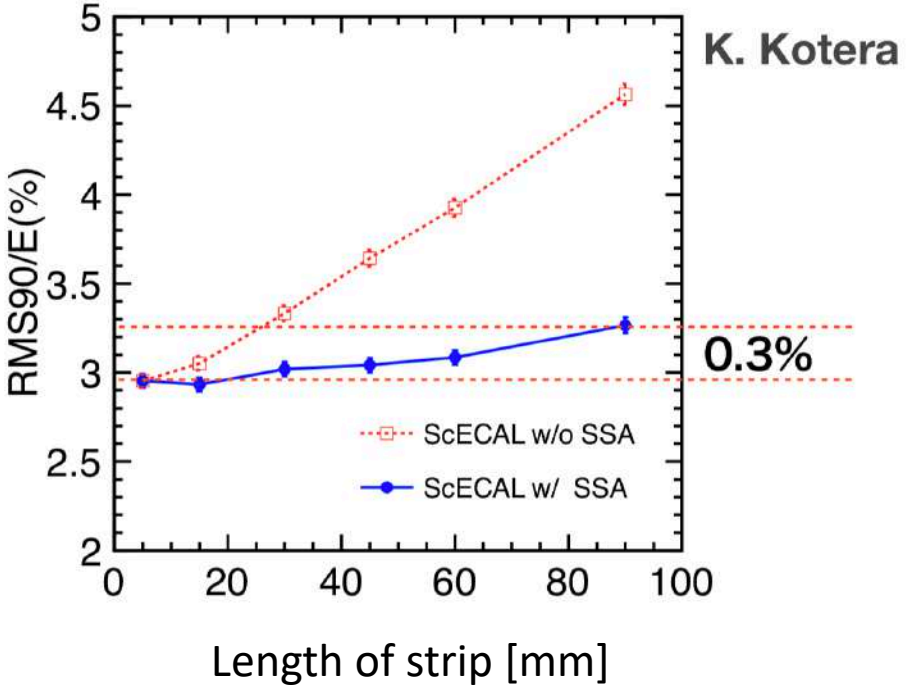


- No significant difference at longer strip
  ➡ Cluster size is smaller than strip length

- Saturation not worsened with longer strip

Jet Energy Resolution with Longer Strip

- Preliminary MC study done by Shinshu group
- JER slightly worsened for longer strip due to ghost hits and pile-up
- N. B. not taken into account possible improvements with double readout
  - ➡ Noise reduction by coincidence
  - ➡ Position reconstruction



- We have to simulate the effect of DR to estimate how much this deterioration can be improved

Summary

- New readout method with double SiPM has been proposed to improve performance of scintillator strip for Sc-ECAL
- Two configurations for double SiPM readout with dimples have been tested
- They both work more or less as expected although some issues should still be understood
- About 22 mm position resolution was obtained from charge and timing difference

Outlook

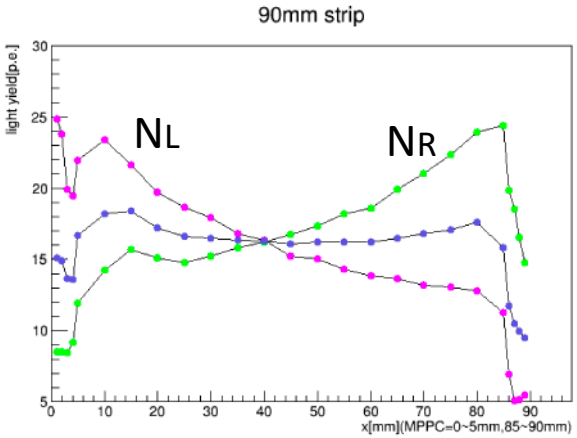
- Based on lab. test results, determine the design of double readout strip mounted on Sc-ECAL prototype

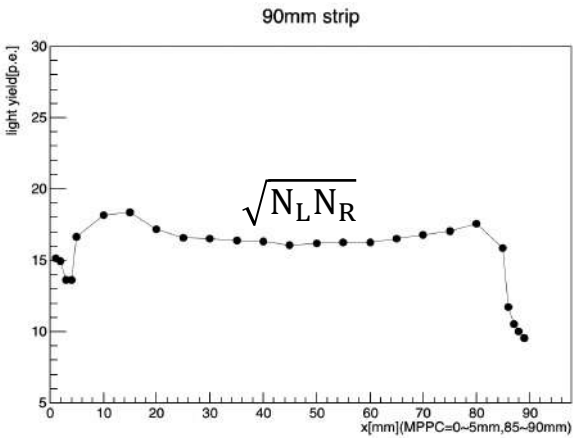
  ➡ Detection layers with double readout will be constructed by beginning of next year
  ➡ Test beam experiment for Sc-ECAL prototype will be done later next year

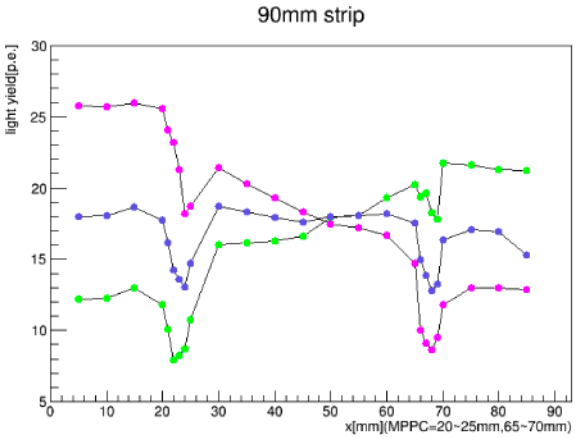
- MC study on calorimeter performance with 90mm strips with double SiPM readout

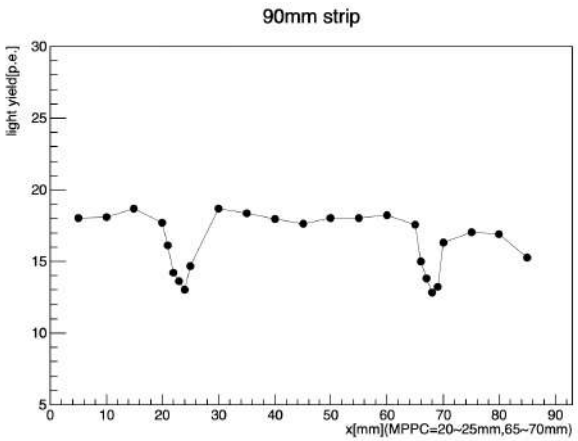
Backup

- Geometric average of 90mm results









- These are more flat than summing responses

Backup

- Position dependence of timing difference for
  90mm strip with double readout in middle of strip (x = 0~45mm)