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

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ILD & ECAL

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

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

- Technology options for ECAL

  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

  Si-ECAL (5 x 5 mm^2 silicon pad)
    ➡ Excellent S/N of silicon sensor
    ➡ Expensive

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

ILD & ECAL
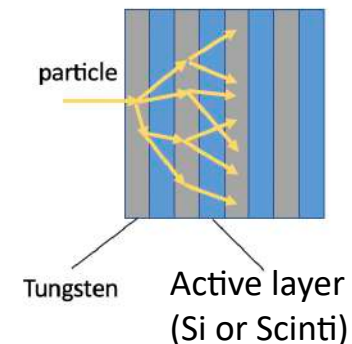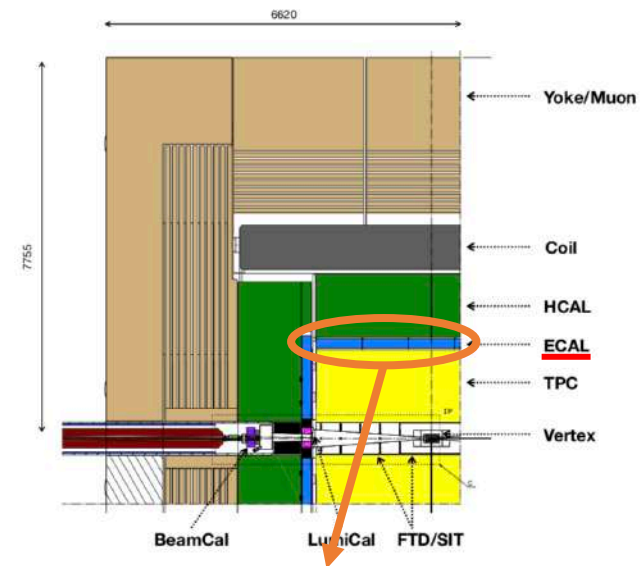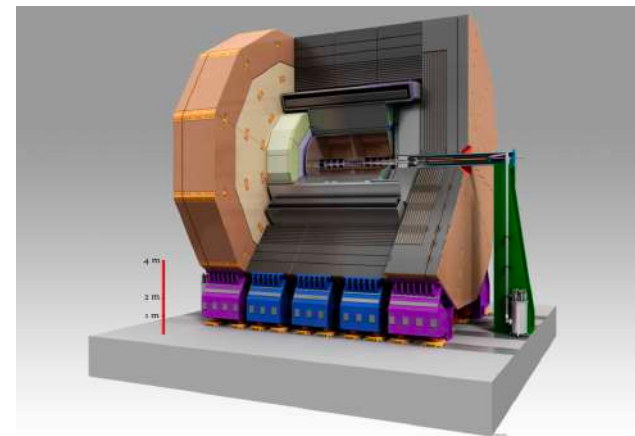
Sc-ECAL

・ EM calorimeter with strip-shaped plastic scintillator readout by SiPM

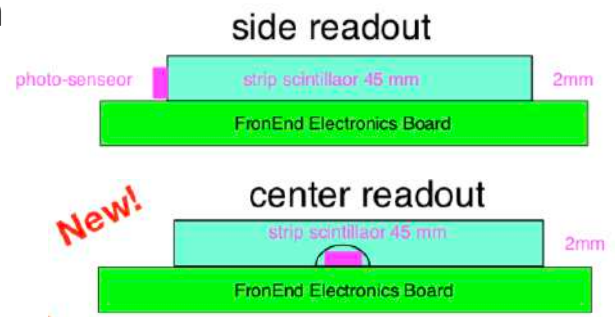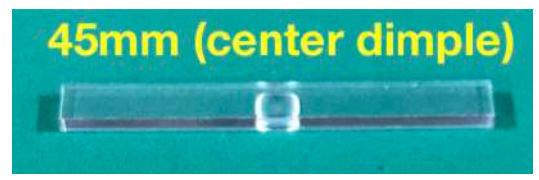・ Virtual 5×5 mm^2 cell segmentation by strip x-y configuration
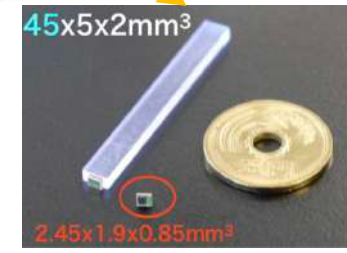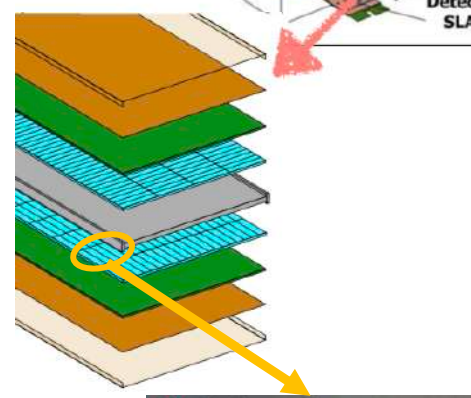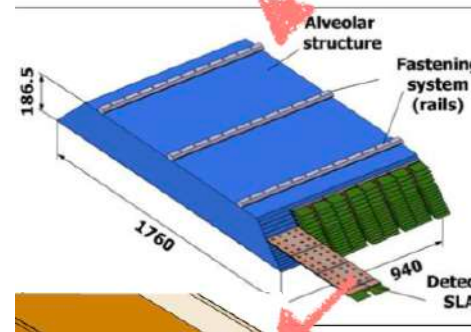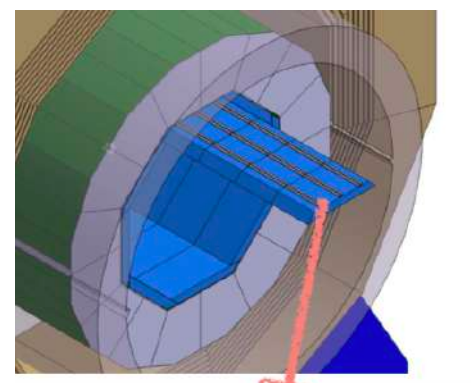
Ghost hit : From two or more simultaneous hits

・ 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

45mm (center dimple)

side readout

photo-senseor | strip scintillaor 45 mm | 2mm
FronEnd Electronics Board

New! center readout

strip scintillaor 45 mm | 2mm
FronEnd Electronics Board

45x5x2mm³

2.45x1.9x0.85mm³

Sc-ECAL

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

➡ MPPC with 10-15μm pixel developed by Hamamatsu

10μm pitch

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%

15μm pitch
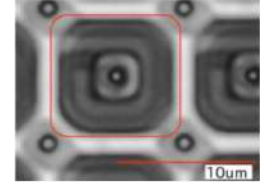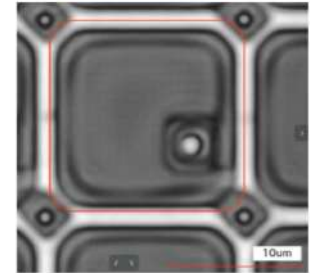
➡ 15μm with higher gain and PDE would be a better choice from S/N viewpoint
➡ However, S/N may not be enough even with 15μm
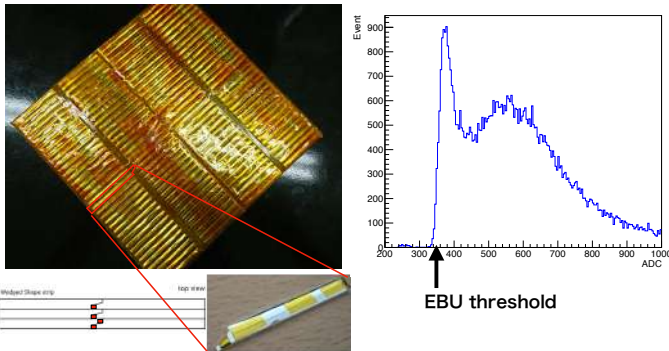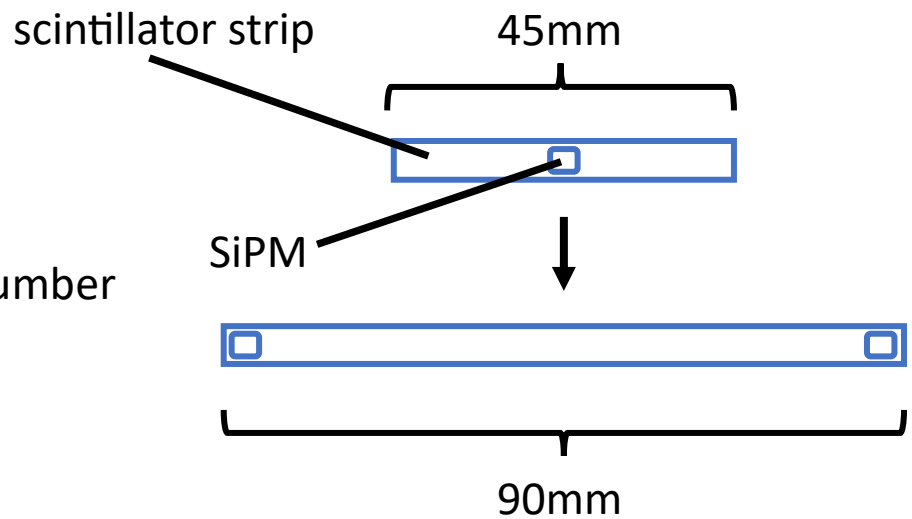

Test beam experiment with 15μm pixel MPPC
by Shinshu Univ.

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

Double SiPM readout

scintillator strip

45mm

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

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

SiPM

90mm

- 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

Npe

X
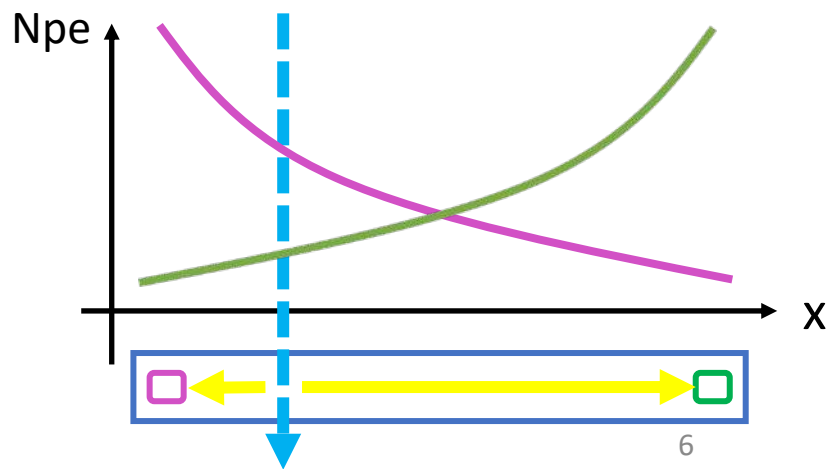
Double SiPM readout for Sc-ECAL prototype

- **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**
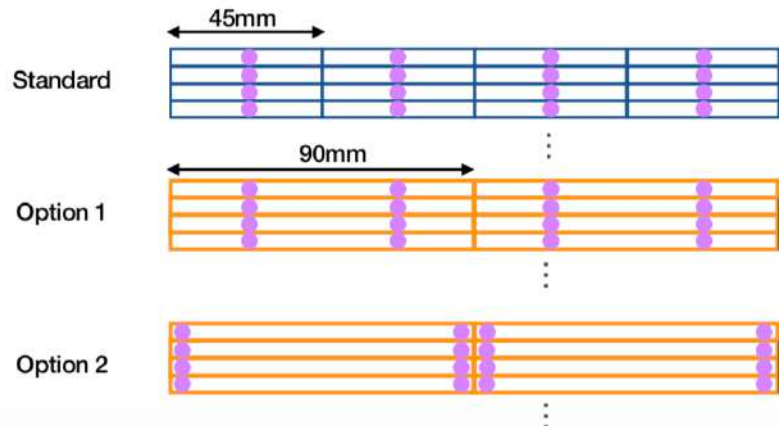
- Two possibilities of implementation
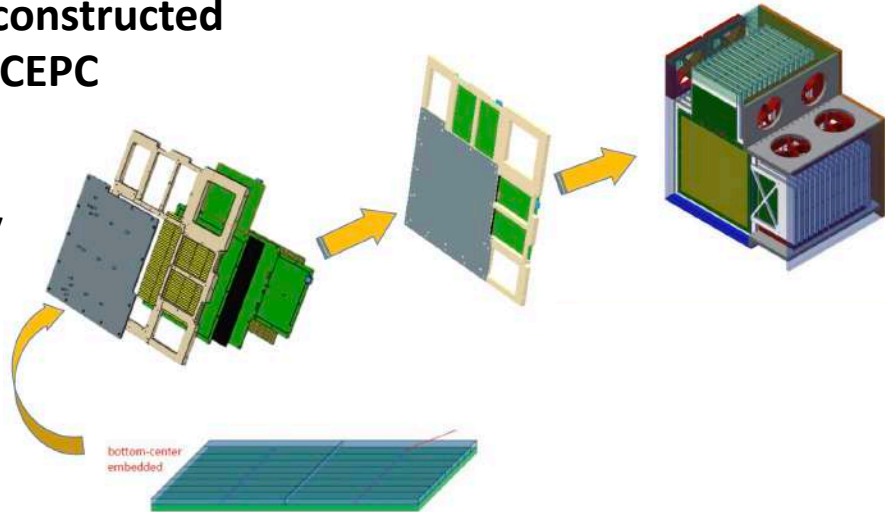
Option 1
  - Two SiPMs in the middle of the strip
  - SiPM positions compatible with standard readout PCB
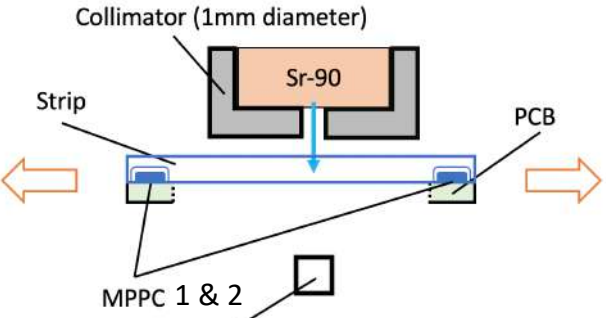
Option 2
  - Two SiPMs at the strip ends
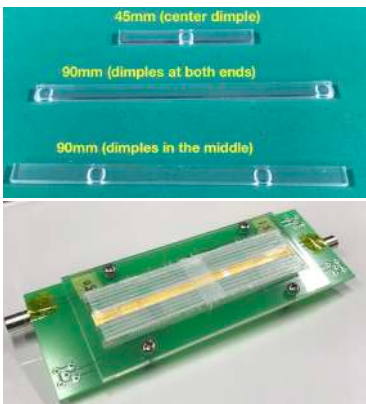 - Need to modify SiPM positions on readout PCB

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

Setup

Collimator (1mm diameter)
Sr-90
Strip
PCB
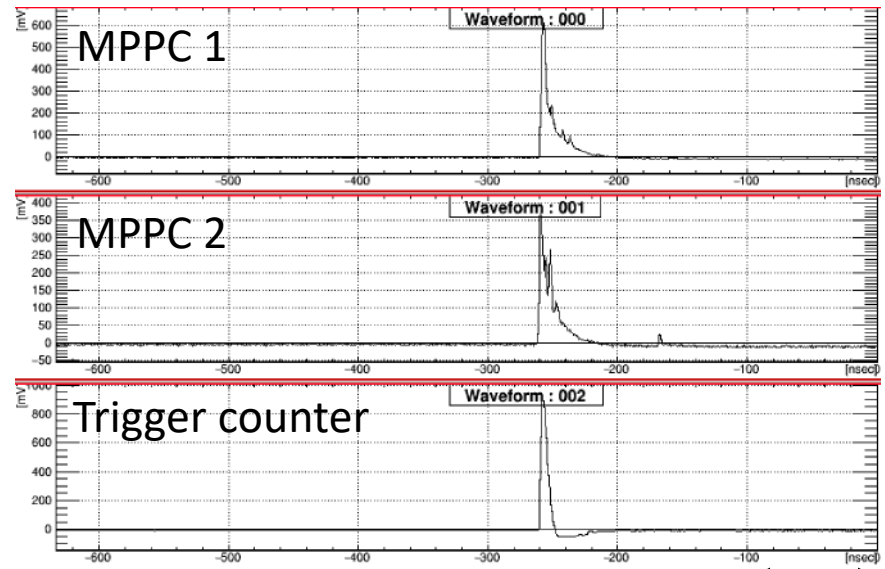MPPC 1 & 2
Trigger counter (5×5×5 mm³ plastic scinti.+SiPM)

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

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

V_{op} : ~ 68V
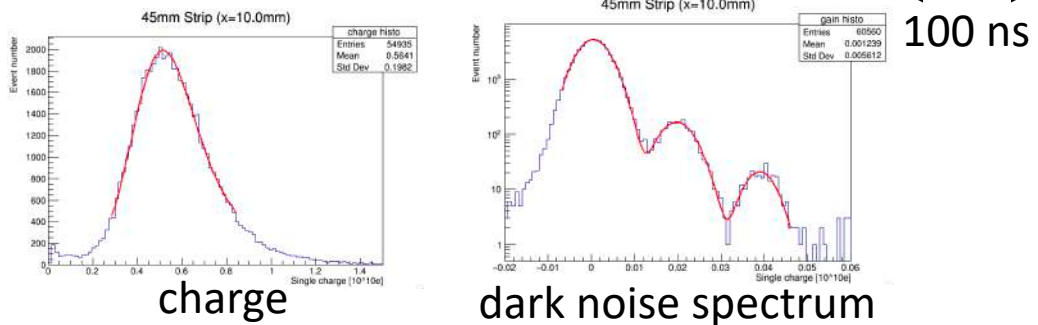
Waveform digitizer

MPPC 1

MPPC 2
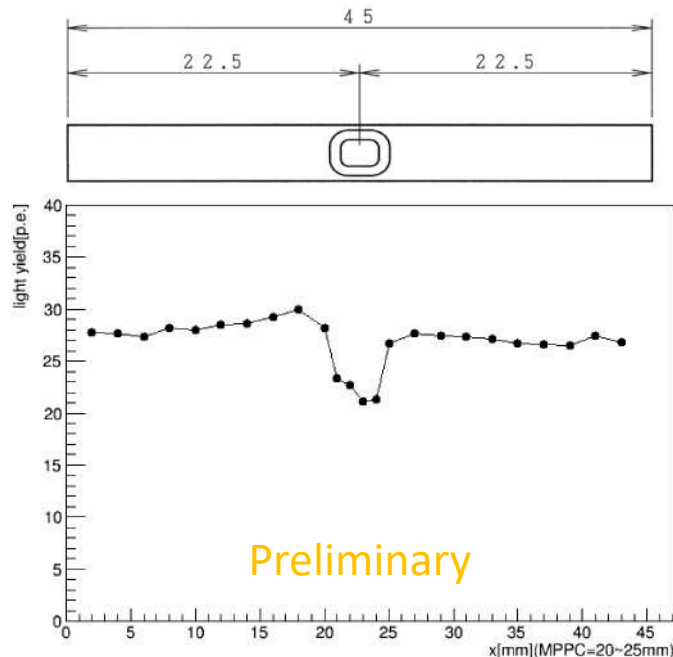
Trigger counter

100 ns

· Measurement
  · Position dependence of N_{pe}
    for 2 types of 90mm strip

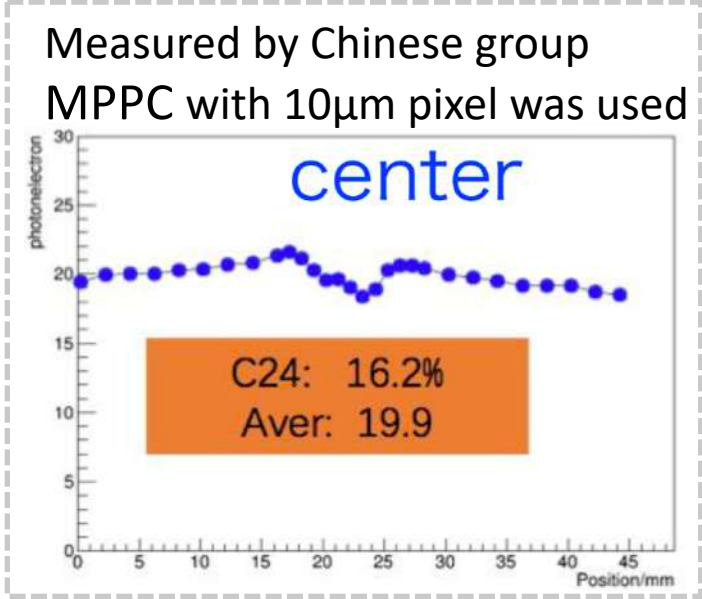 · 45mm strip with center dimple
    was also tested for comparison

charge   dark noise spectrum

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

Results : 45mm strip with single readout

Preliminary

Measured by Chinese group
MPPC with 10μm pixel was used

center

C24: 16.2%
Aver: 19.9

- 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

  ➡ Difference in shape of dimple?
  ➡ Further optimization of dimple shape is planned

Results : 90mm strip with double readout at strip end
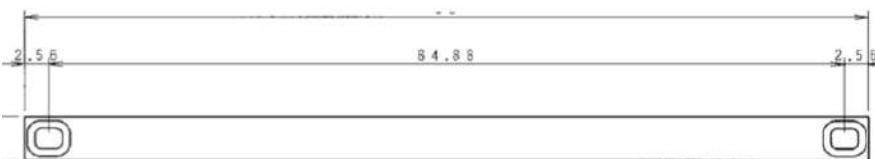
90mm strip

light yield[p.e.]

N_L+N_R

N_L N_R

Preliminary

x[mm](MPPC=0~5mm,85~90mm)

More or less flat response with sum of two readouts

Npe ~ 35 (average)
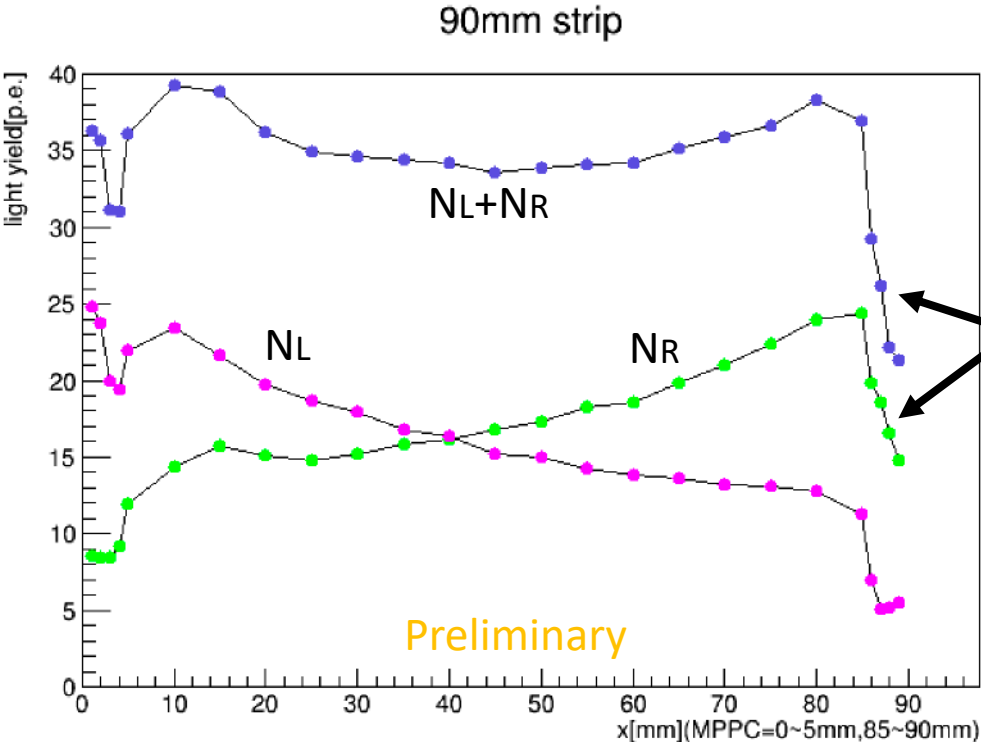
· Larger than 45mm strip
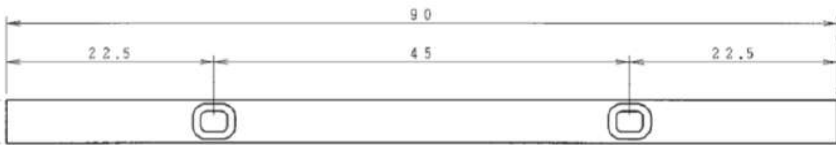· Even lower for each MPPC
  ➡ less saturation

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

90mm strip

More or less flat response with sum of two readouts

Npe ~ 35 (average)

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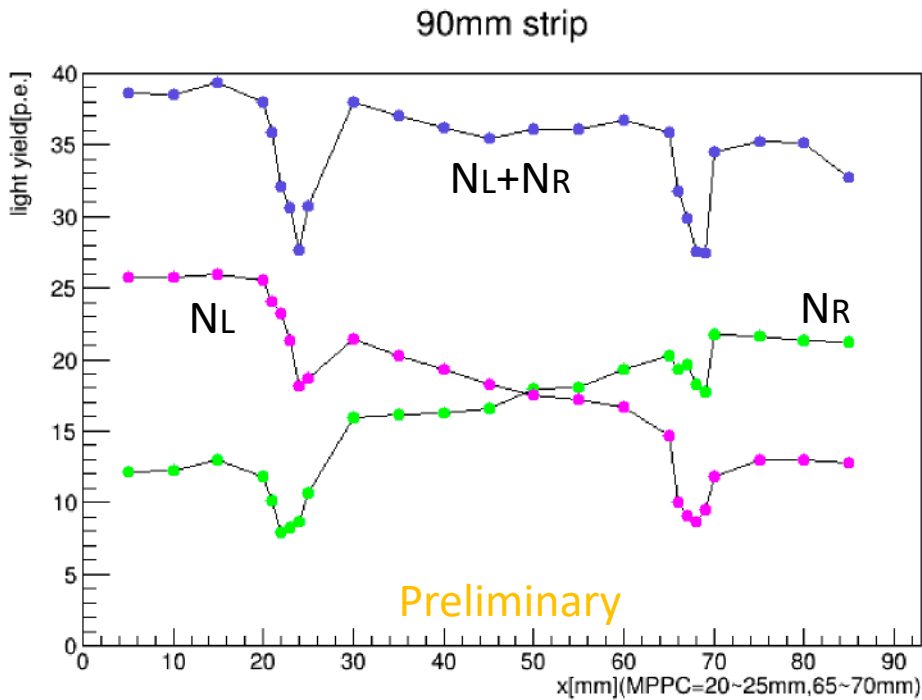・ Even lower for each MPPC

➡ less saturation

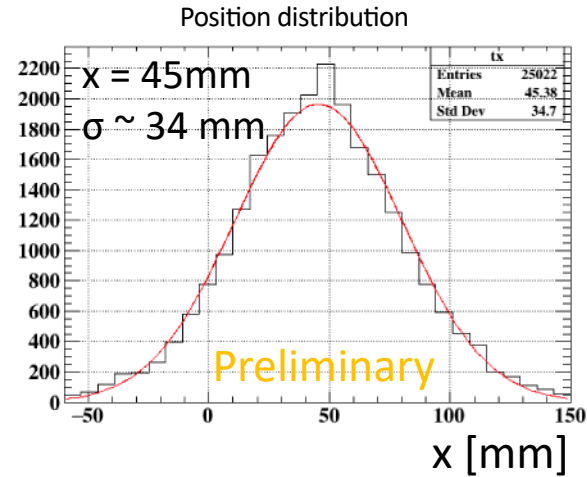**Response curve is slightly slanted**
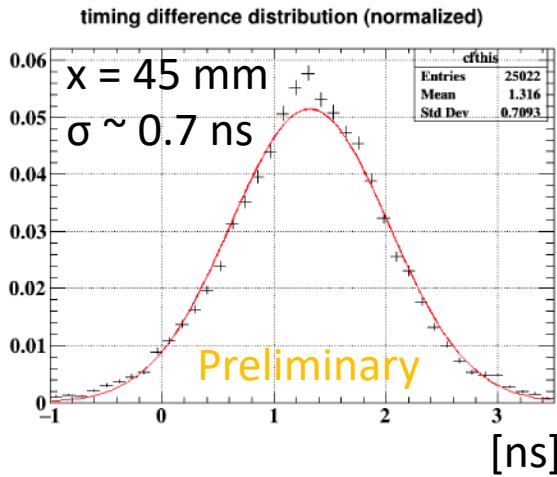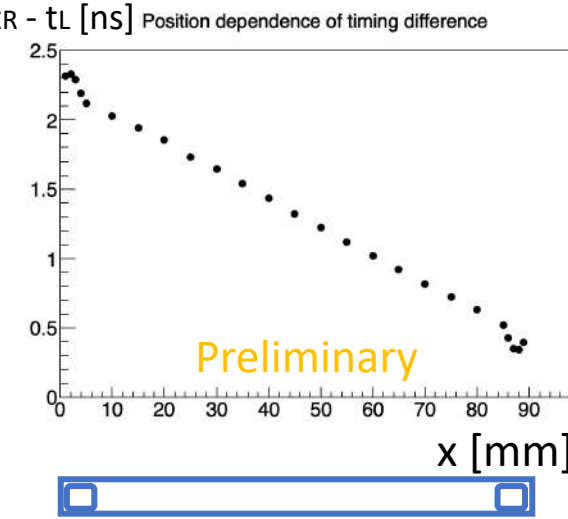
➡ Misalignment?

No position dependence outside dimples

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

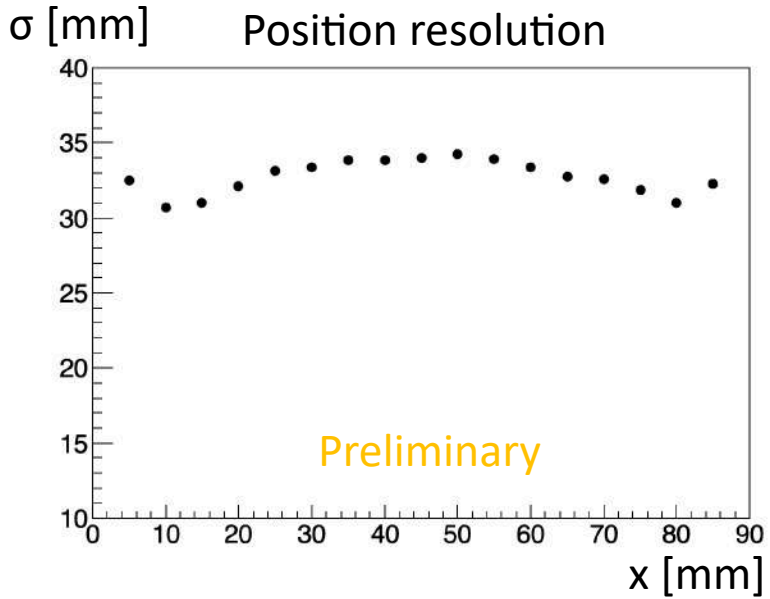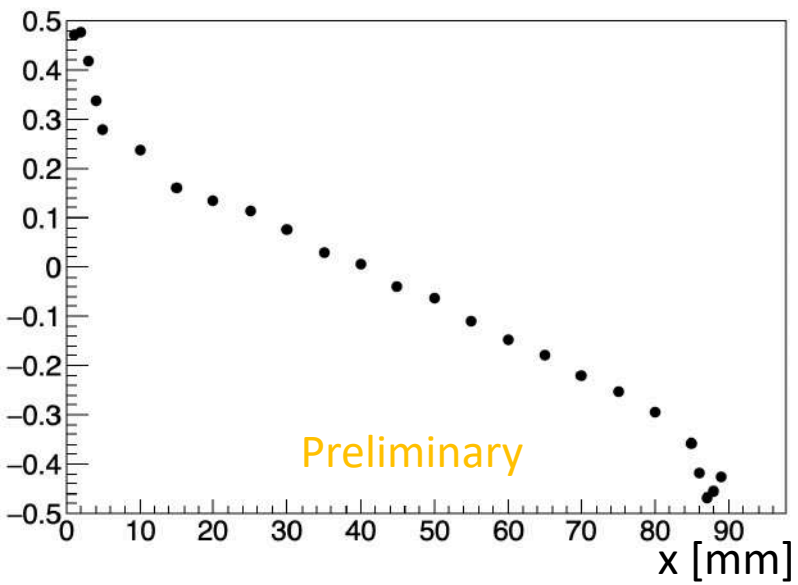➡ N.B. this is a tentative configuration only for prototype

Results : position reconstruction from timing difference

$t_R - t_L$ [ns] Position dependence of timing difference

Preliminary

x [mm]

timing difference distribution (normalized)

x = 45 mm
σ ~ 0.7 ns

cfthis	
Entries	25022
Mean	1.316
Std Dev	0.7093

Preliminary

[ns]

Position distribution

x = 45mm
σ ~ 34 mm

tx	
Entries	25022
Mean	45.38
Std Dev	34.7

Preliminary

x [mm]

· 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 waveform digitizer,
  but it's not possible in the detector.
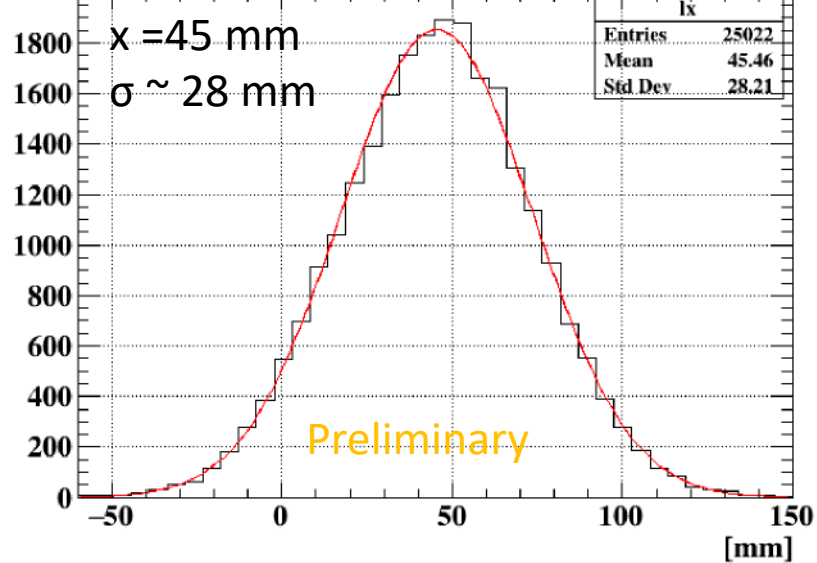➡ Need to improve timing performance of readout
   electronics

σ [mm]   Position resolution

Preliminary

x [mm]

Results : position reconstruction from charge difference

Preliminary

distribution of converted LY difference

x =45 mm
σ ~ 28 mm

lx	
Entries	25022
Mean	45.46
Std Dev	28.21

Preliminary

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

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

σ [mm]   Position resolution
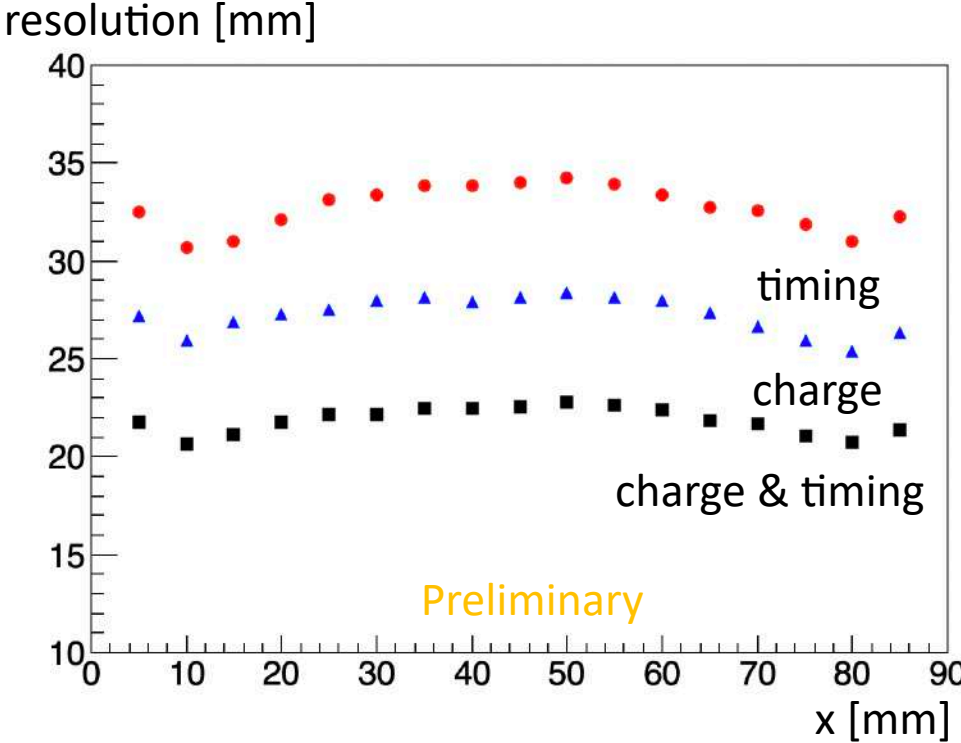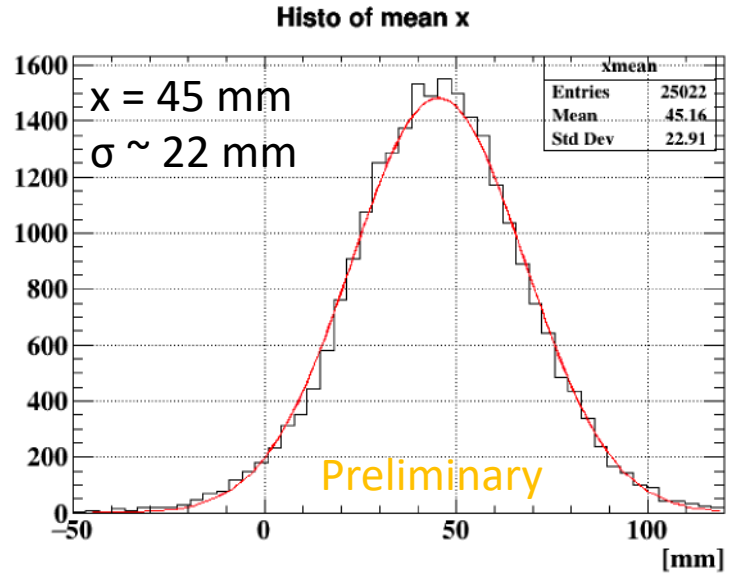

Preliminary
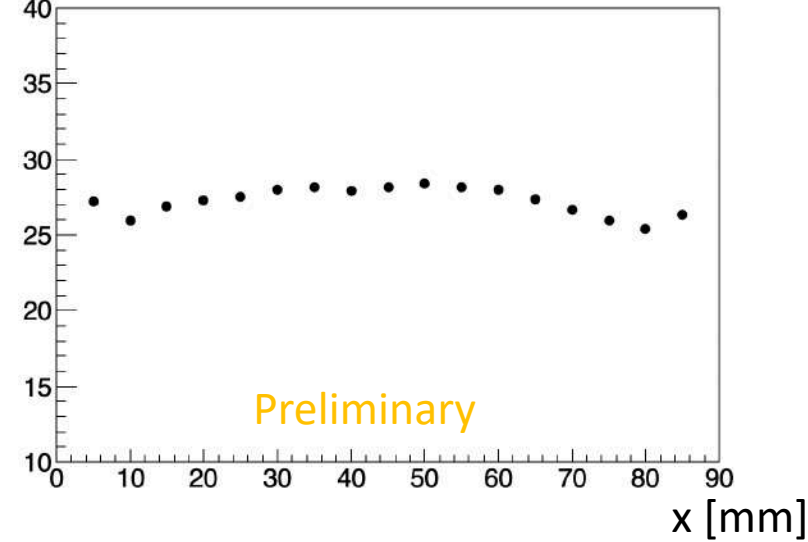
Results : position reconstruction

- 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

x = 45 mm

σ ~ 22 mm

Histo of mean x

xmean	
Entries	25022
Mean	45.16
Std Dev	22.91

Preliminary

[mm]

resolution [mm]

timing

charge

charge & timing

Preliminary

x [mm]

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

- Need further optimization of dimple shape

- About 22 mm 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 end of this year

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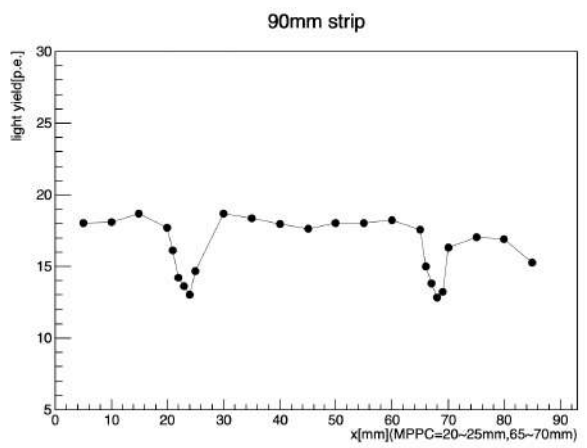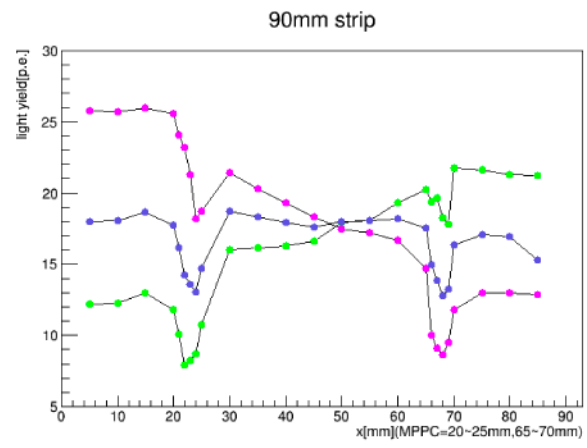
Backup

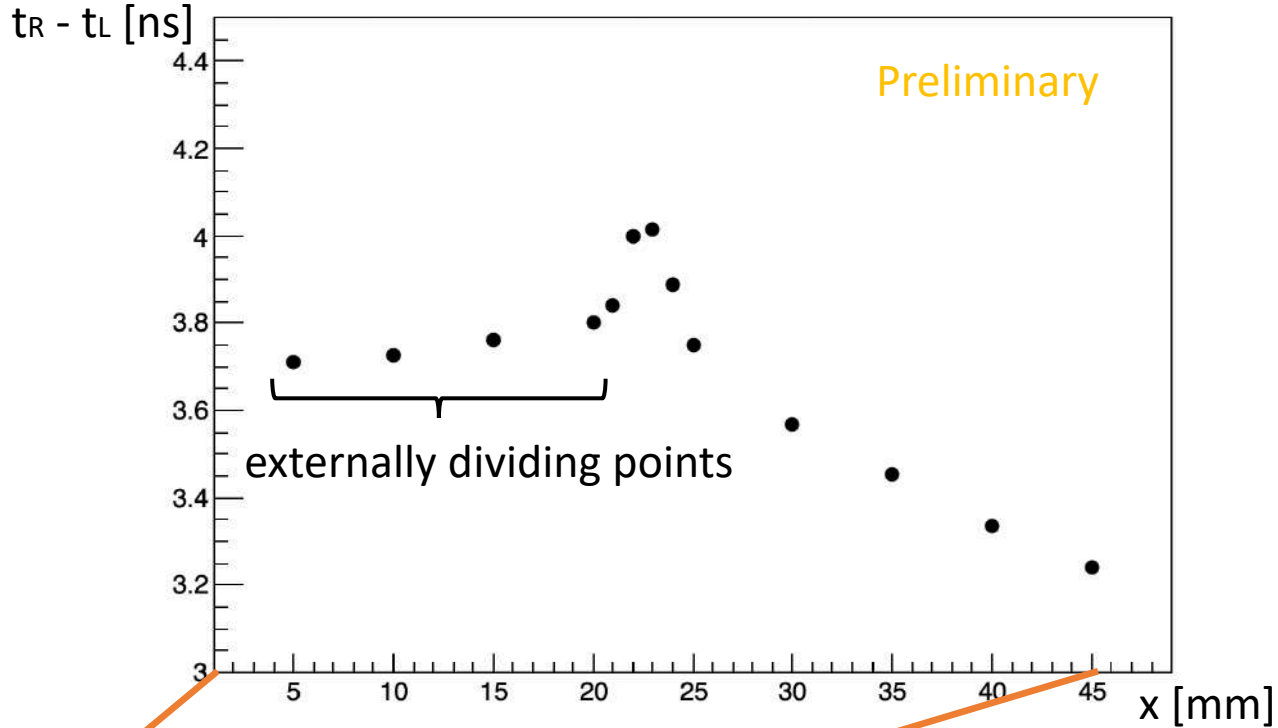- Geometric average of 90mm results
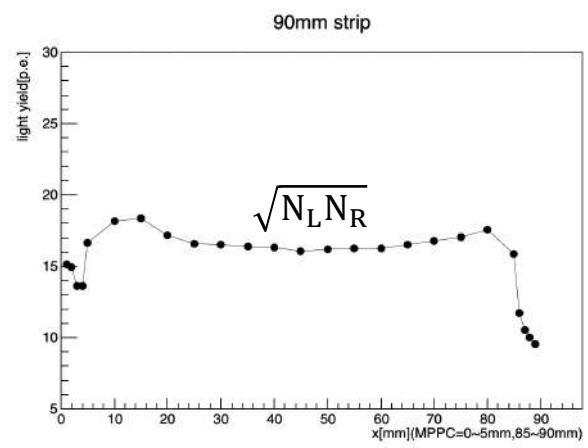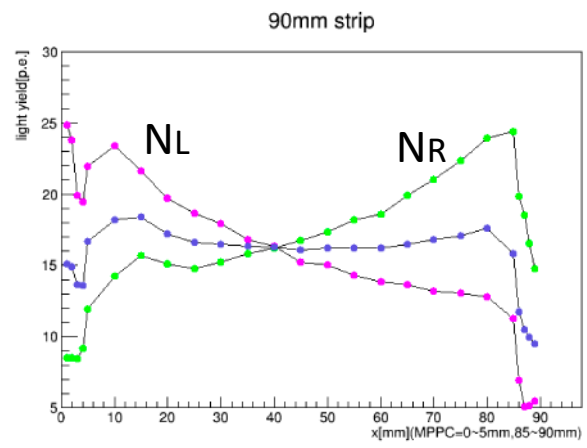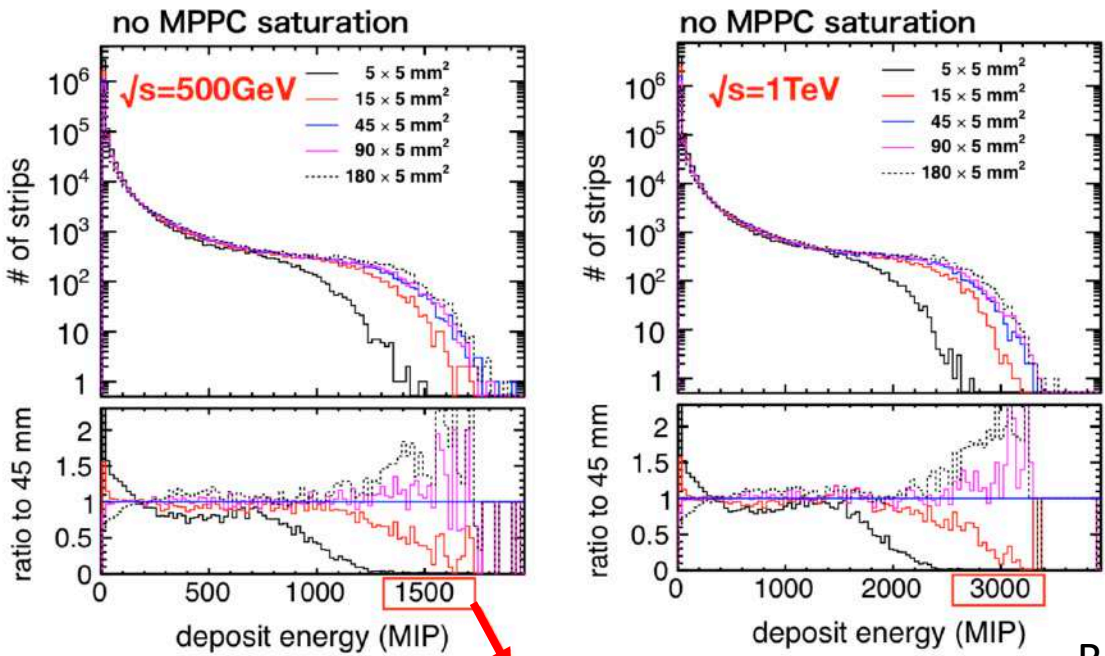

- These are more flat
  than summing responses

Backup

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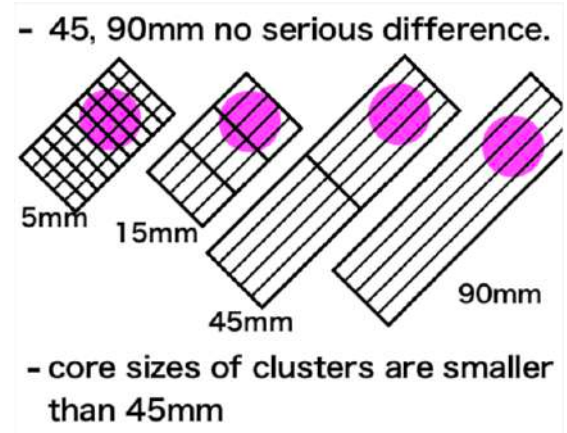 90mm strip with double readout in middle of strip (x = 0~45mm)

Backup

Energy deposit per strip from previous study

· Considering Bhabha events at √s = 500 GeV & 1 TeV

K.Kotera

- 45, 90mm no serious difference.

5mm 15mm 45mm 90mm

- core sizes of clusters are smaller than 45mm

Response of 10 µm-cell SiPM

· 1500MIP → N_{pe} ~ 10k for nominal strip config.

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

· Saturation not worsened with longer strip
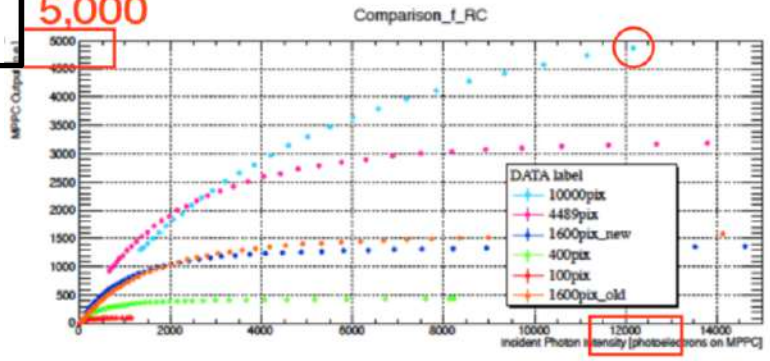
Backup

Jet Energy Resolution

- JER slightly worsened for longer strip due to ghost hits

- Can be improved by
  - ➡ Additional tile layers
  - ➡ Position reconstruction with double SiPM readout