

Development of new SiPM readout method for ILD scintillator electromagnetic 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

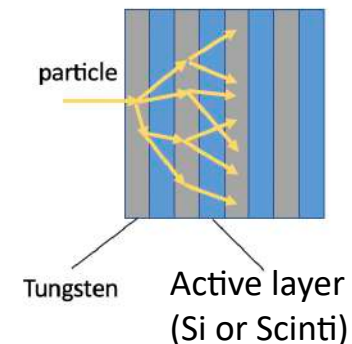
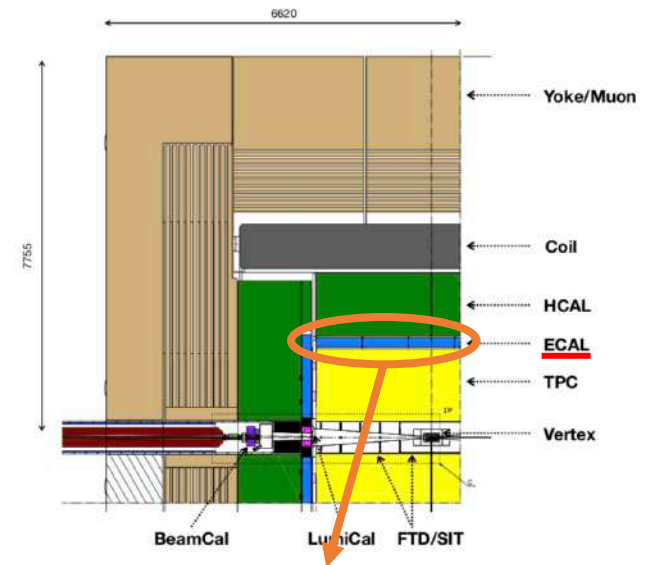
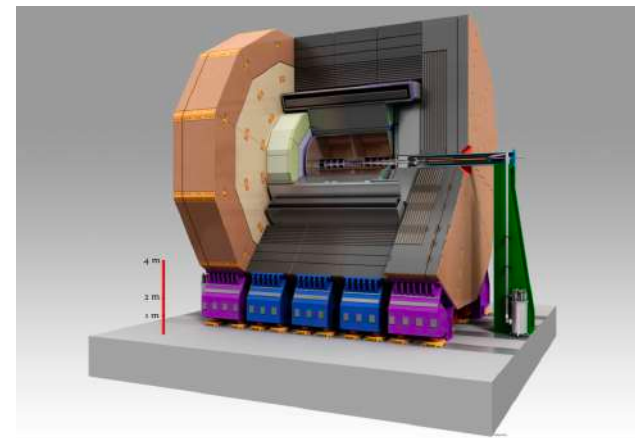
Sc-ECAL (5 x 45 mm² scintillator strip)

- ➔ Moderate S/N of scintillator strip
- ➔ Ten times smaller # of readout channels with comparable calorimeter performance

Si-ECAL (5 x 5 mm² 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



Sc-ECAL

- EM calorimeter with strip-shaped plastic scintillator readout by SiPM
- Virtual $5 \times 5 \text{ mm}^2$ cell segmentation by strip x-y configuration

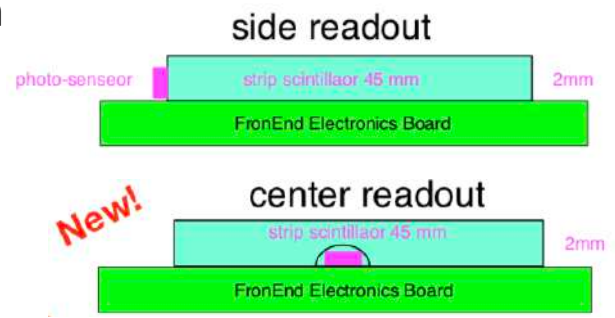
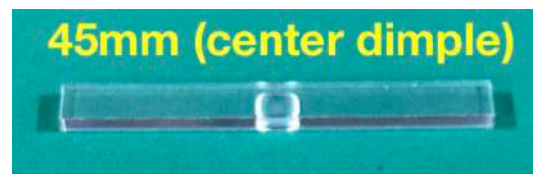
Ghost hit : From two or more simultaneous hits

Possible solution

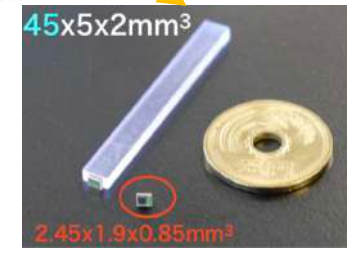
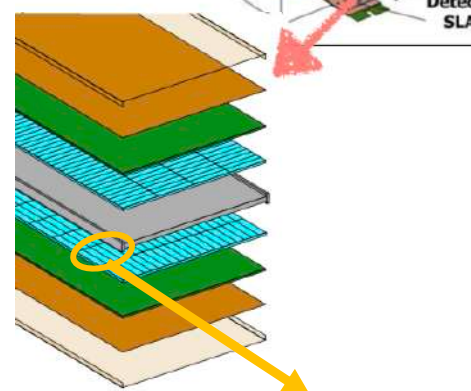
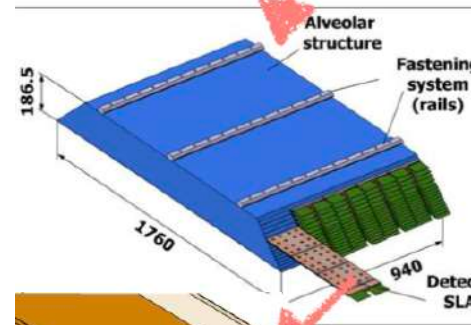
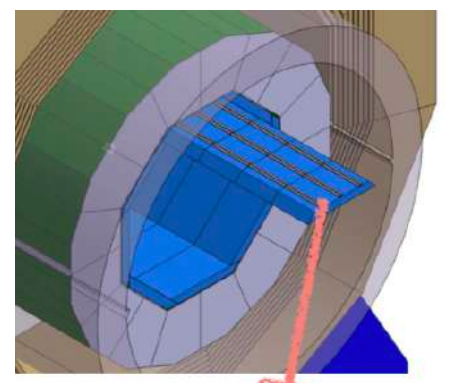
- ➔ Interleaving square scintillator tile (a la AHCAL) to solve ambiguity
- ➔ Position reconstruction by double SiPM readout (to be discussed later)

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

➔ Suitable for large scale production



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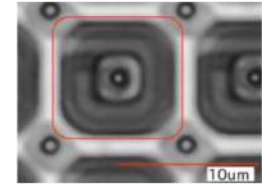
Sc-ECAL

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

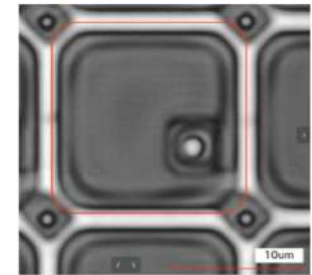
➔ MPPC with 10-15 μm pixel developed by Hamamatsu

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

10 μm pitch

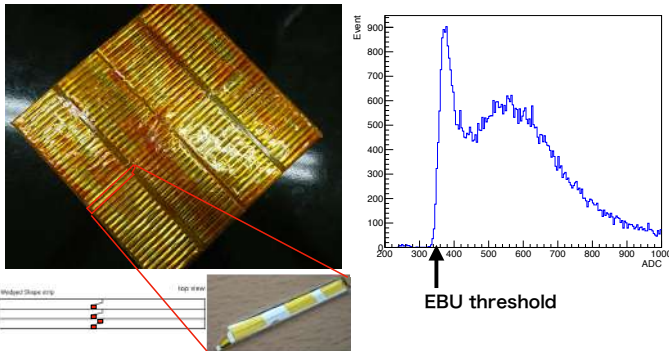


15 μm pitch



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

➔ However, S/N may not be enough even with 15 μm

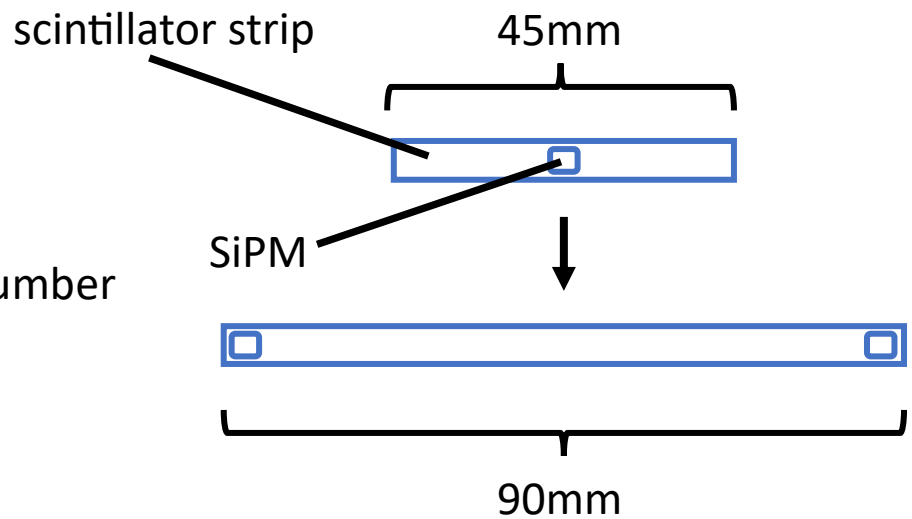


Test beam experiment with 15 μm pixel MPPC by Shinshu Univ.

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

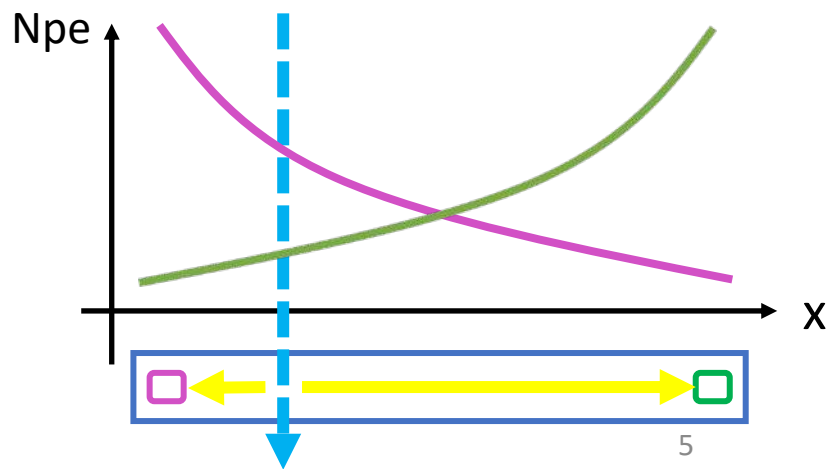
Double SiPM readout

- 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



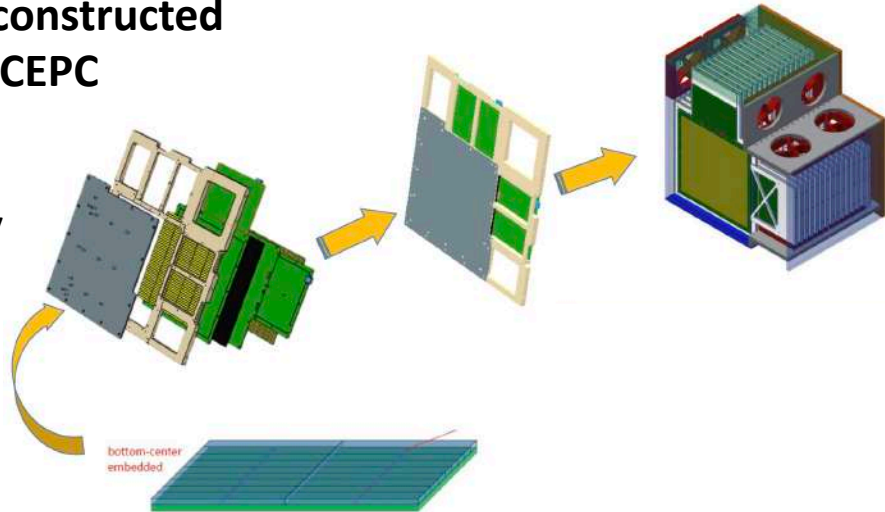
Double SiPM readout for Sc-ECAL prototype

- **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

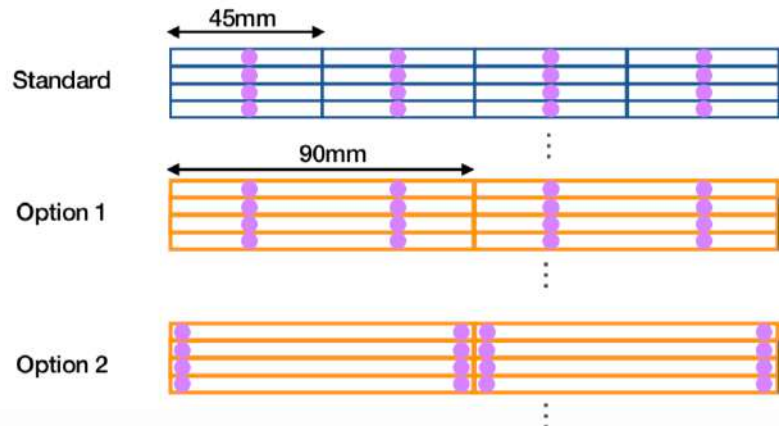


Option 1

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

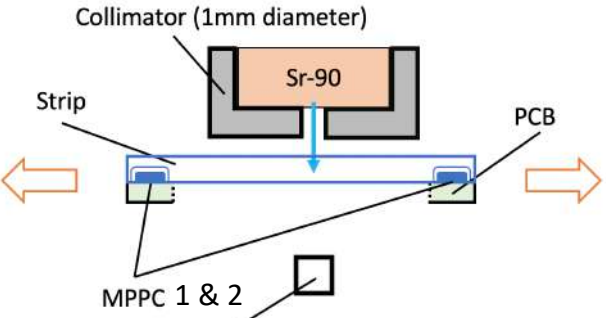
Option 2

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

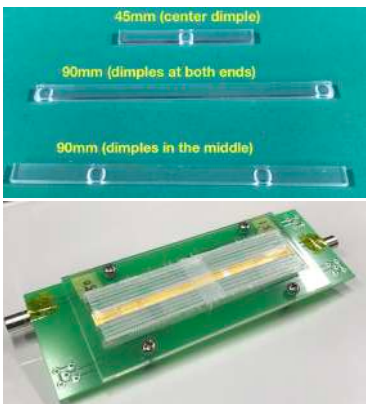


- **Prototype tests for double readout for two options were performed**

Setup



Trigger counter ($5 \times 5 \times 5 \text{ m}^3$ plastic scinti.+SiPM)

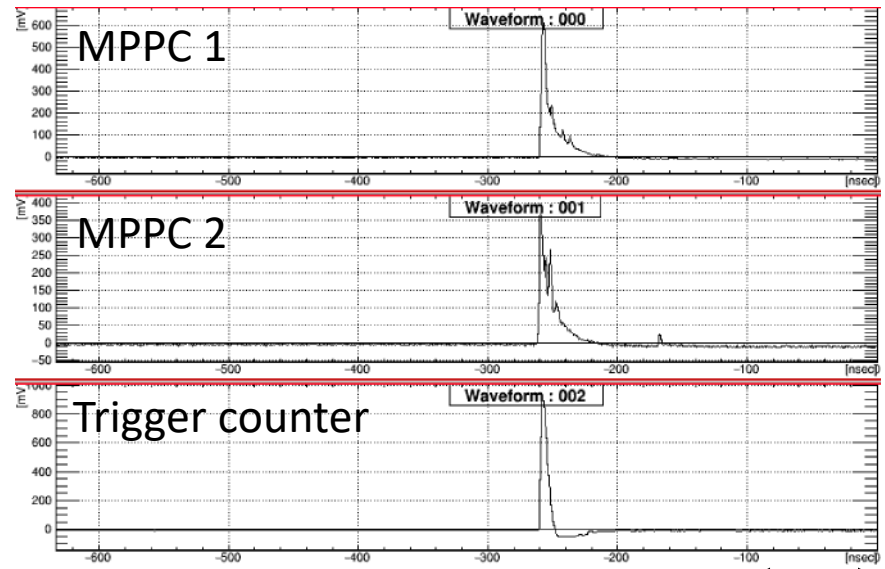


Plastic scintillator : EJ-212 Reflector : ESR2 (laser-cut)

MPPC : S12571-015P (1 x 1 mm² 15μm-pixel)

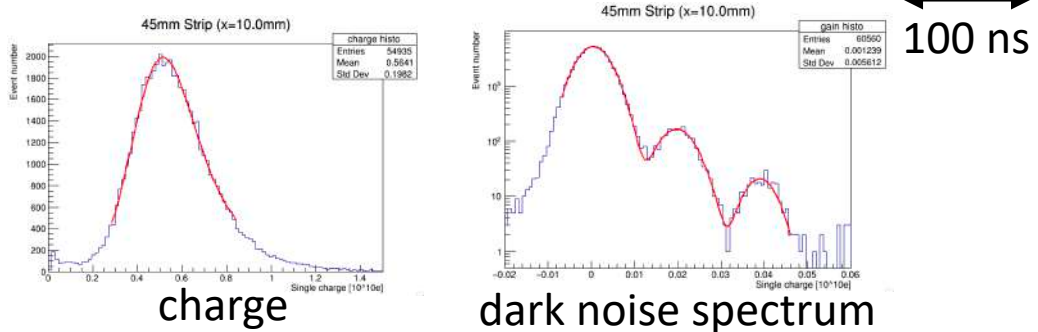
V_{op} : ~ 68V

Waveform digitizer



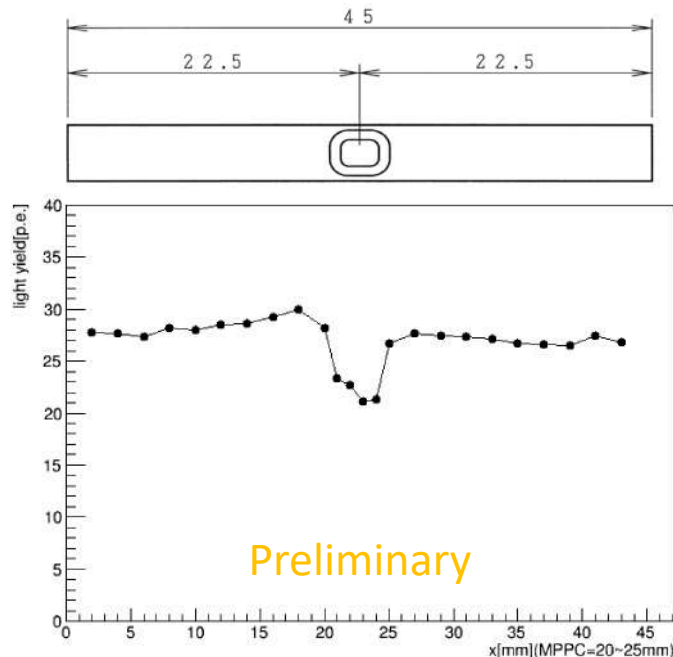
Measurement

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

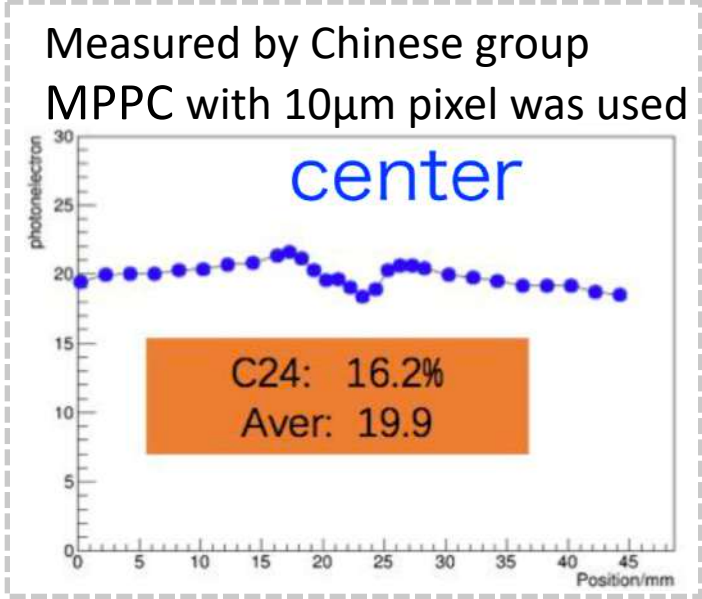


Light yield = (charge peak)/(single p.e. charge)

Results : 45mm strip with single readout



Preliminary



- 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

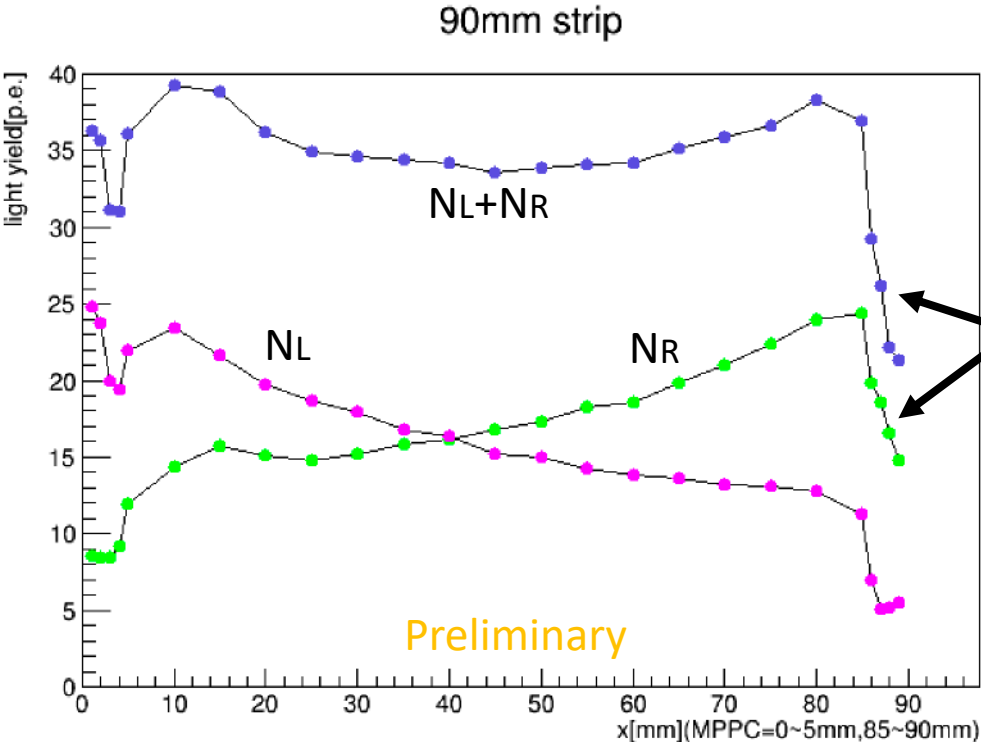
Results : 90mm strip with double readout at strip end



More or less flat response with sum of two readouts

N_{pe} ~ 35 (average)

- Larger than 45mm strip
- Even lower for each MPPC
- ➔ less saturation



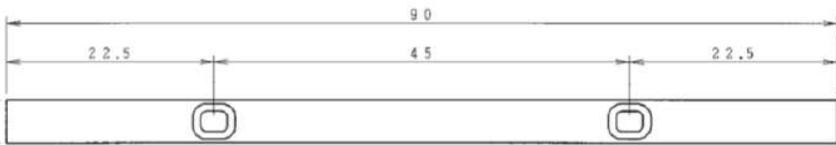
Strange behavior at right end

- Misalignment?
- Under investigation

Position-dependent N_{pe} 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

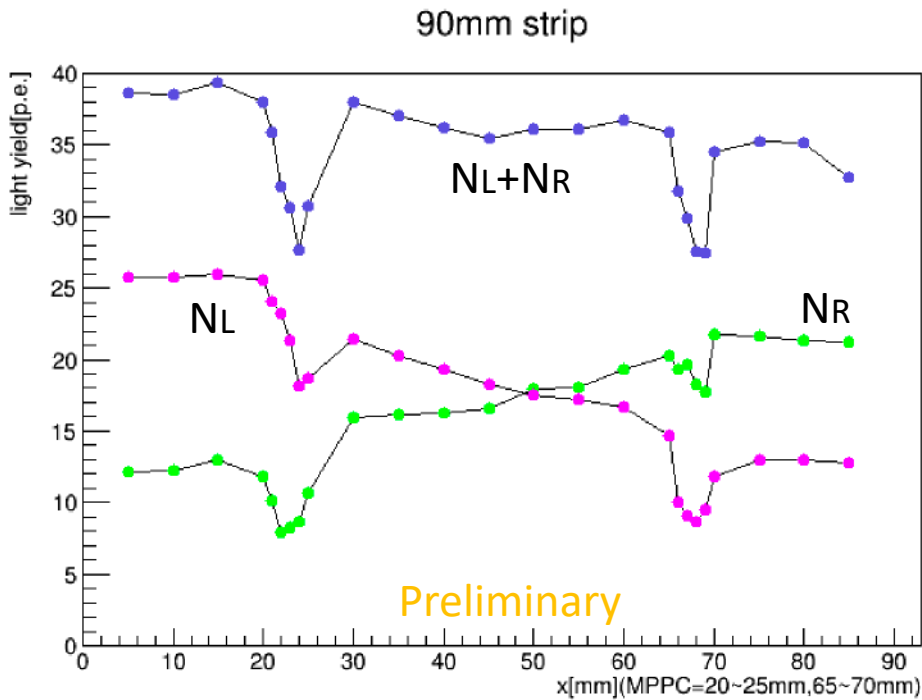
Response curve is slightly slanted

➔ Misalignment?

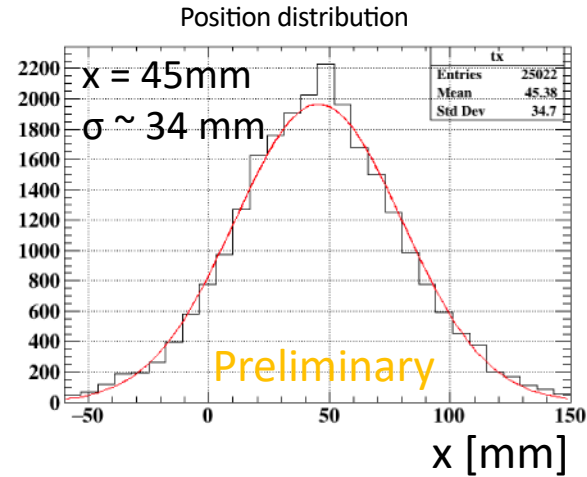
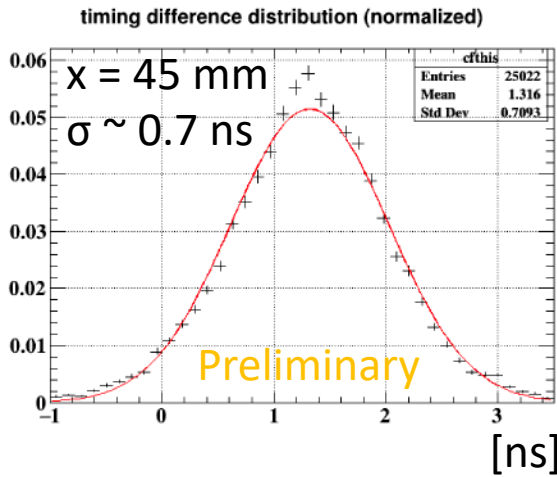
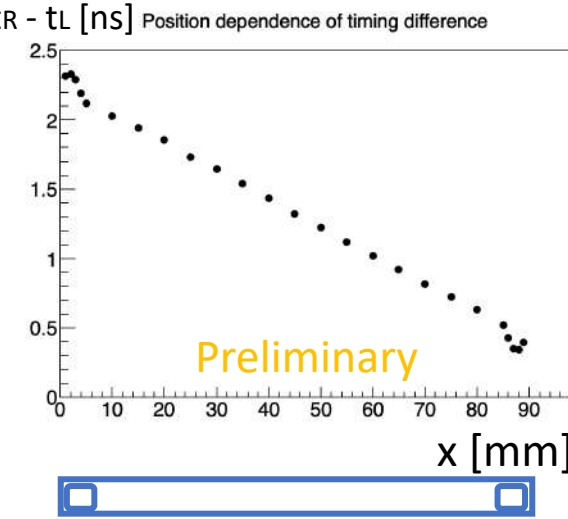
No position dependence outside dimples

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

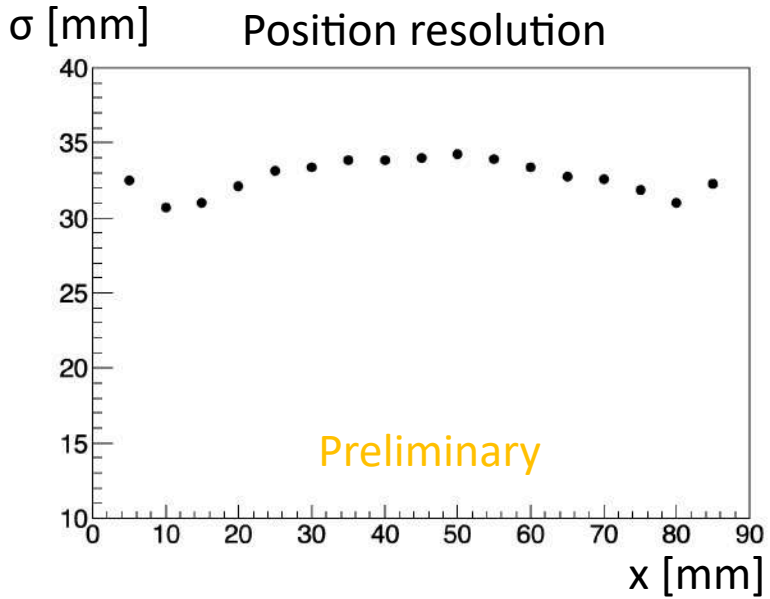
➔ N.B. this is a tentative configuration only for prototype



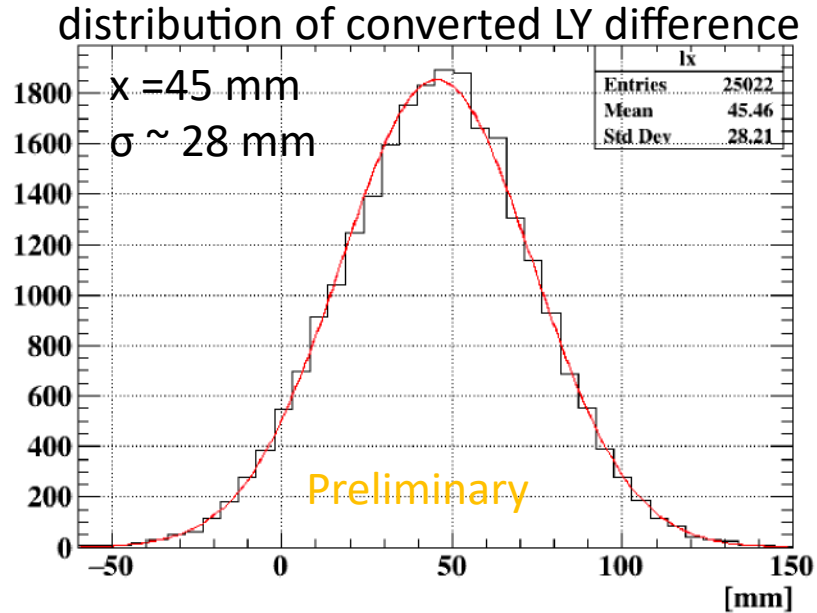
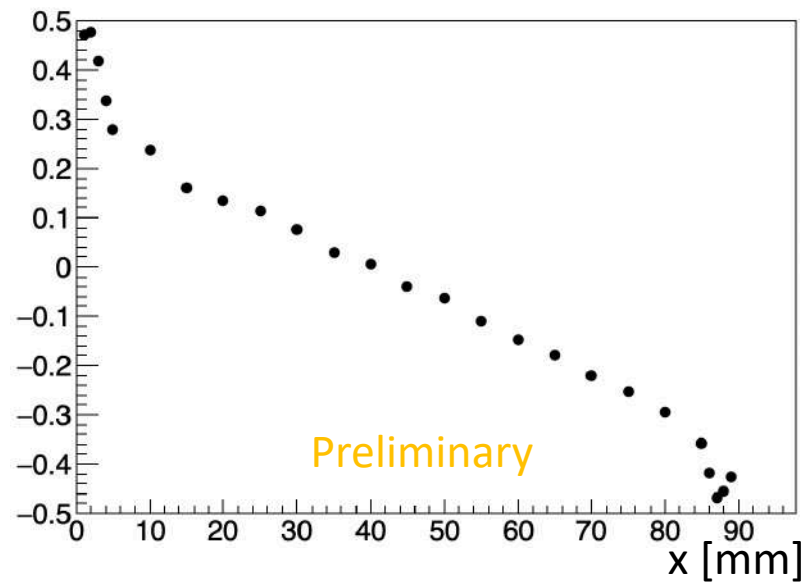
Results : position reconstruction from timing difference



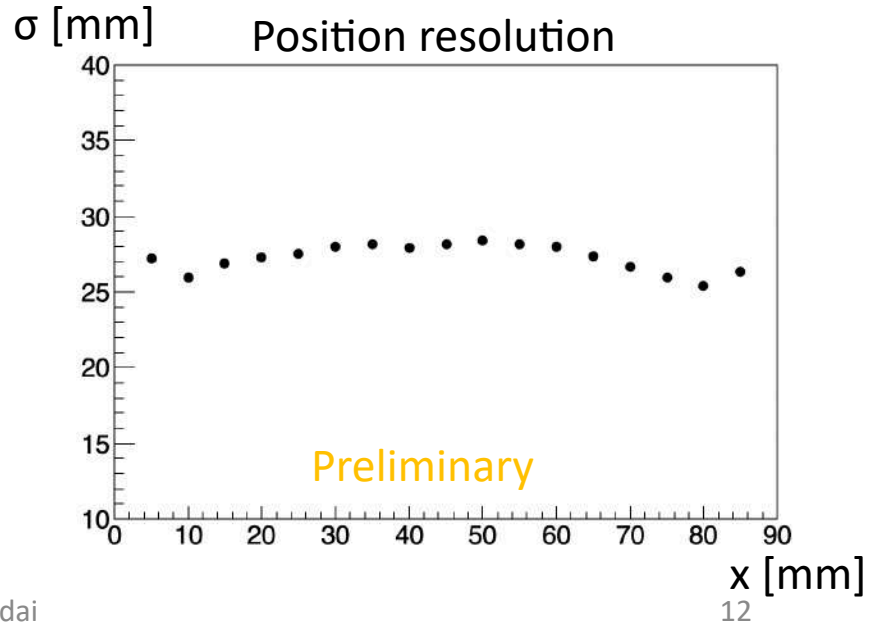
- Dimples at both ends
- Position reconstruction by timing difference
 - ➔ $\sigma \sim 32$ mm was obtained with preliminary setup (for $x = 5 \sim 85$ mm)
- This lab. study was performed with waveform digitizer, but it's not possible in the detector.
 - ➔ Need to improve timing performance of readout electronics



Results : position reconstruction from charge difference



- vertical axis : $\frac{LY(L) - LY(R)}{LY(L) + LY(R)}$
- $\sigma \sim 27$ mm was obtained ($x = 5 \sim 85$ mm)



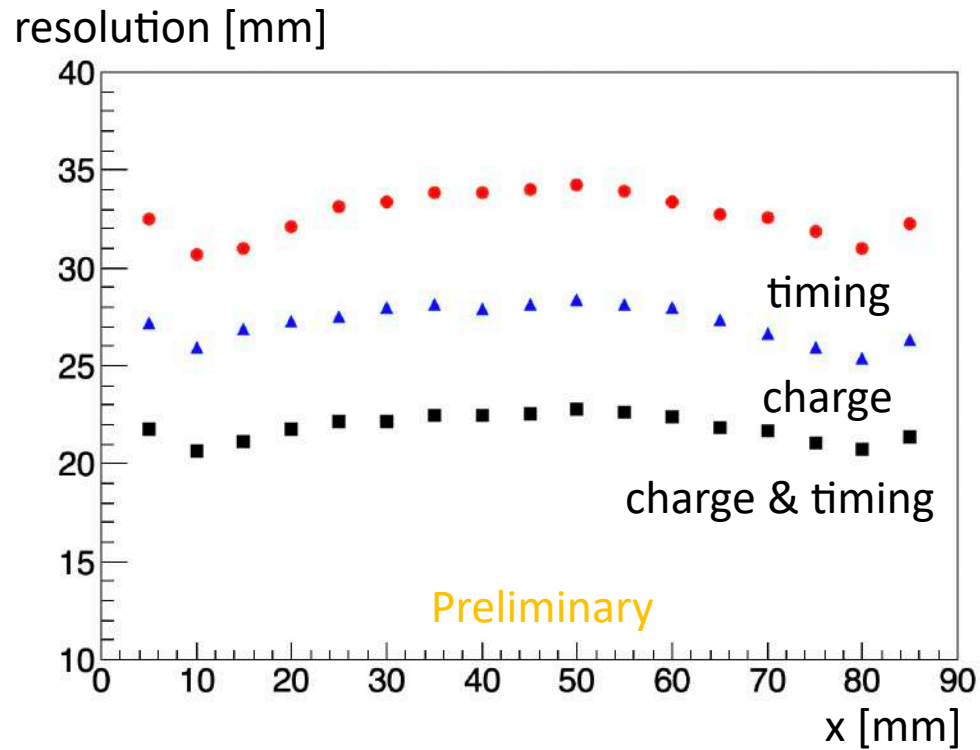
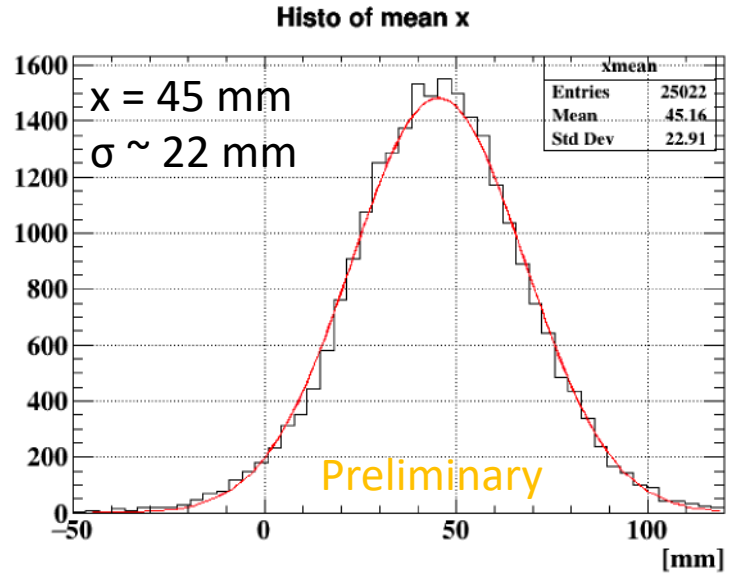
Results : position reconstruction

- Position reconstruction from weighted mean of charge and timing difference

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

- $\sigma \sim 22$ 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



Summary

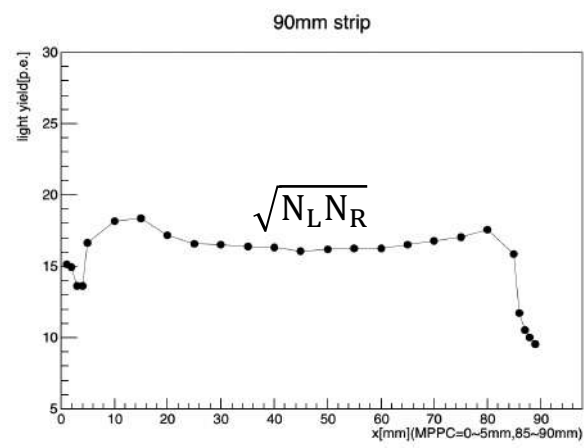
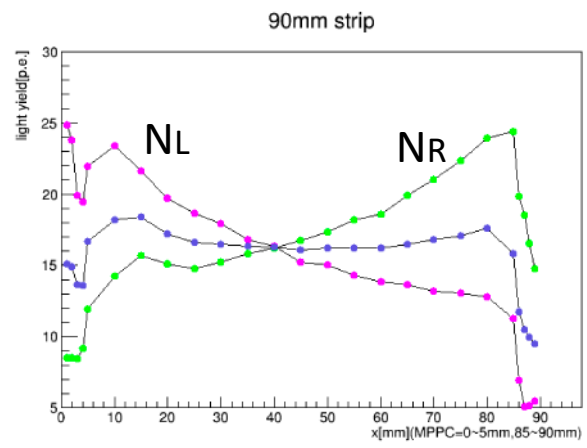
- New readout method with double SiPM has been proposed to improve performance of scintillator strip for Sc-ECAL
- Two configurations for double SiPM readout with dimples have been tested
- They both work more or less as expected although some issues should still be understood
- Need further optimization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

Outlook

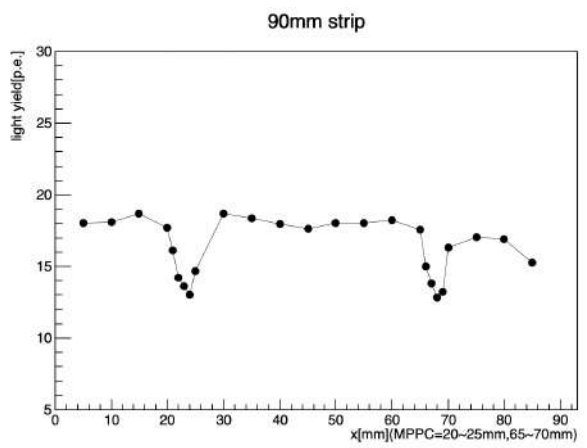
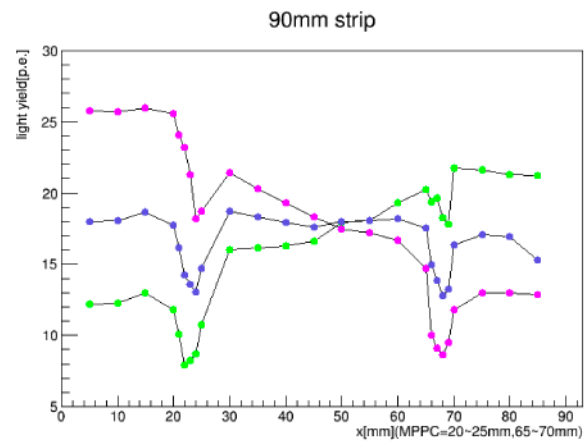
- Based on lab. test results, determine the design of double readout strip mounted on Sc-ECAL prototype
 - ➔ Detection layers with double readout will be constructed by end of this year
- MC study on calorimeter performance with 90mm strips with double SiPM readout

Backup

- Geometric average of 90mm results

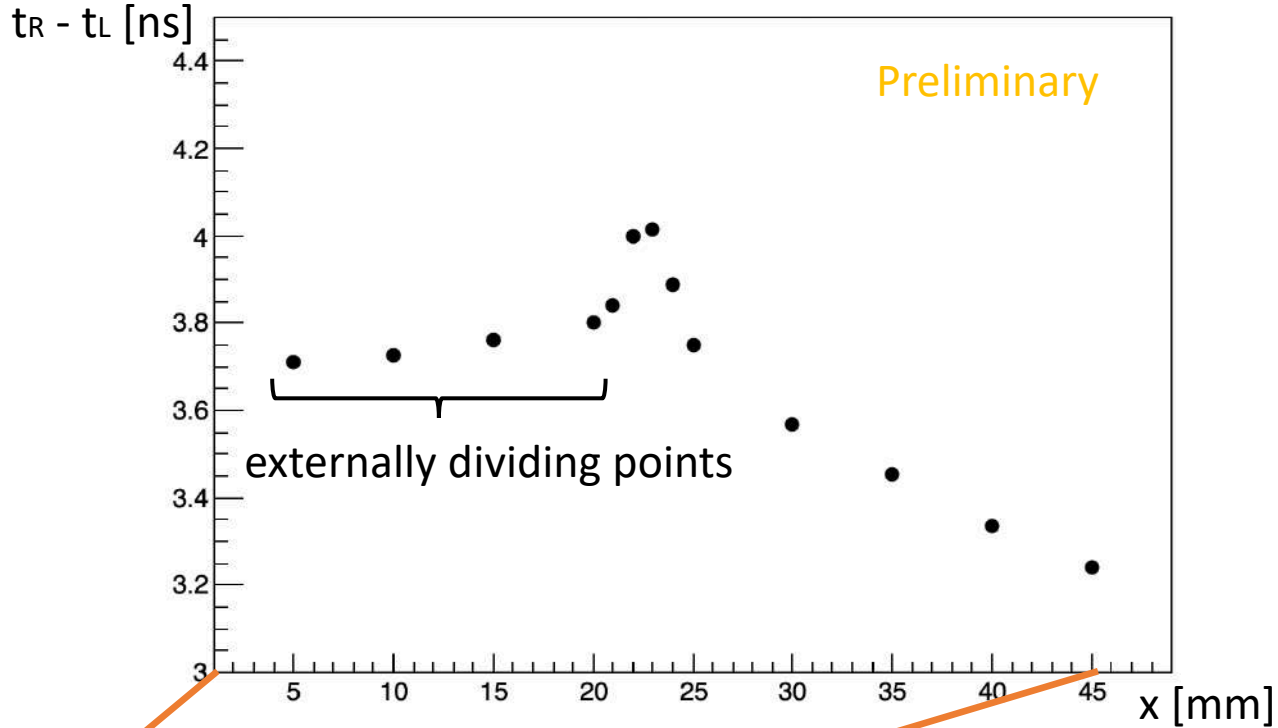


- These are more flat than summing responses



Backup

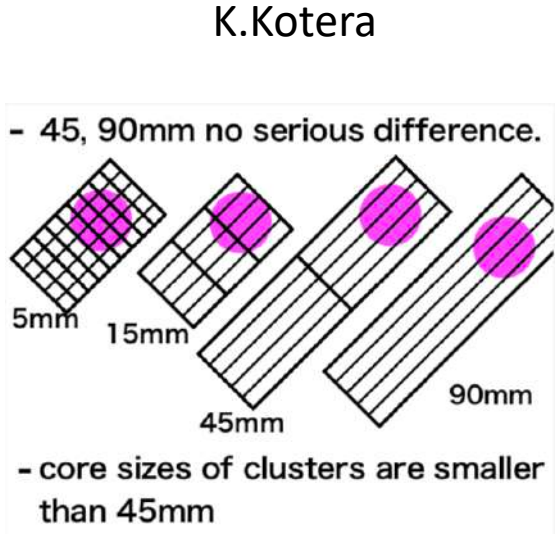
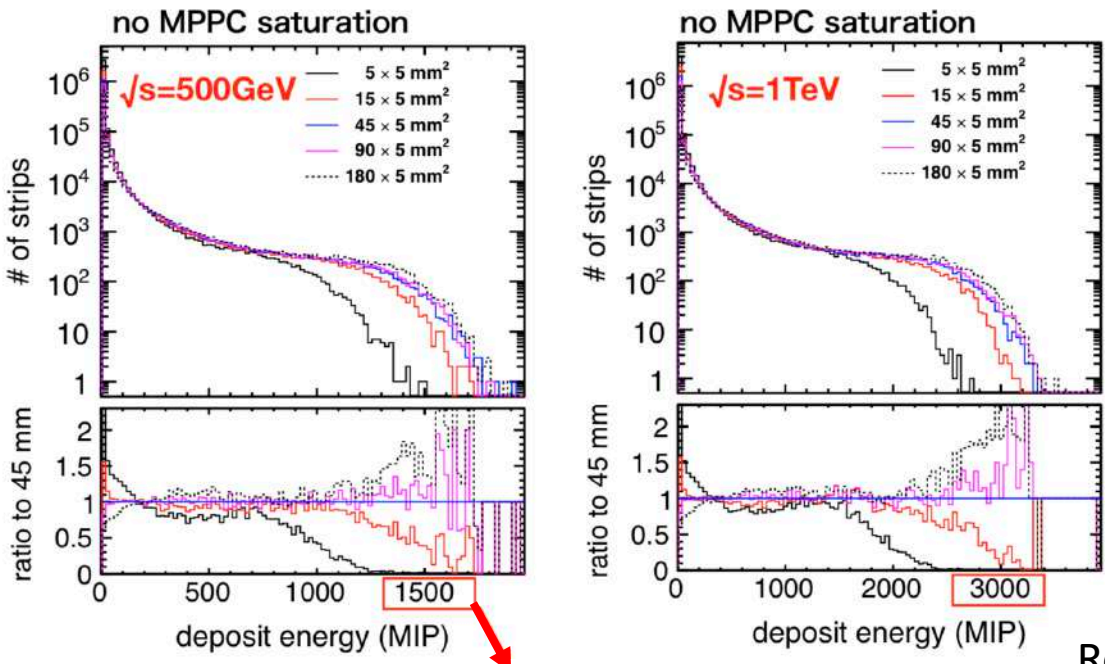
- Position dependence of timing difference for 90mm strip with double readout in middle of strip ($x = 0 \sim 45\text{mm}$)



Backup

Energy deposit per strip from previous study

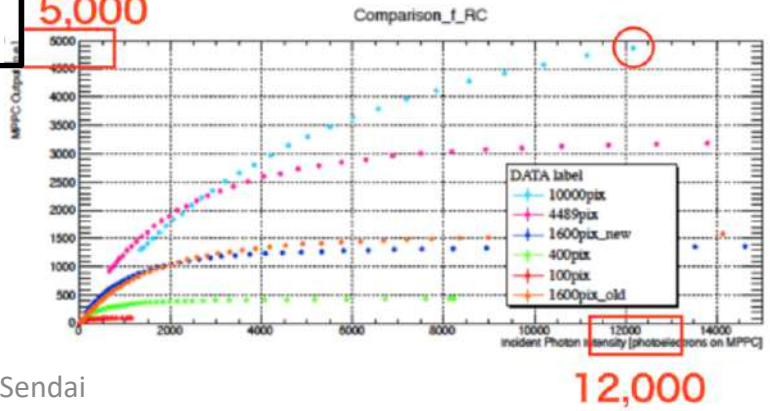
- Considering Bhabha events at $\sqrt{s} = 500 \text{ GeV}$ & 1 TeV



• 1500MIP $\rightarrow N_{pe} \sim 10k$ for nominal strip config.

- No significant difference at longer strip
 \rightarrow Cluster size is smaller than strip length
- Saturation not worsened with longer strip

Response of $10 \mu\text{-cell}$ SiPM



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

