Study on time resolution of scintillator-SiPM unit for Sc-ECAL

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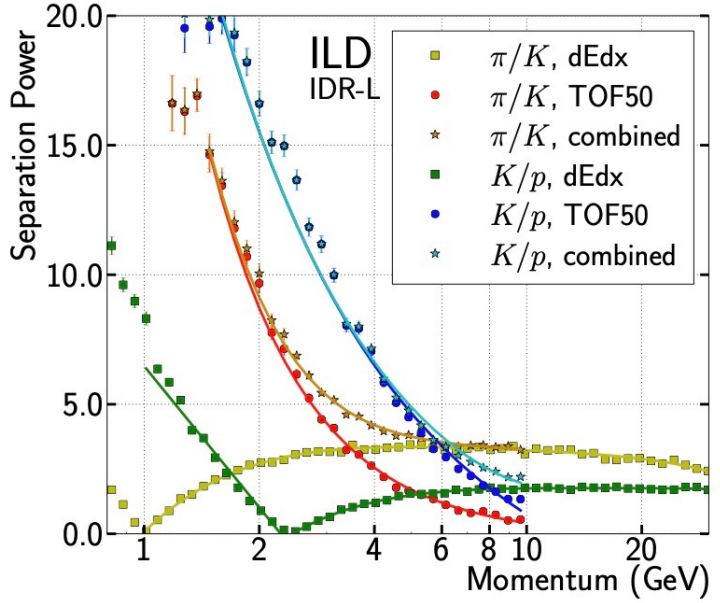
Good time resolution as an additional value

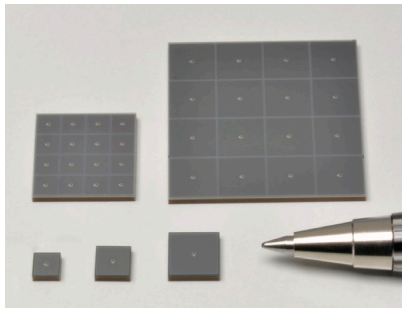
- Good timing resolution is important for improving performance in many aspects of the detector.
  - ➢ Improvement of separation power to identify π/K/p
  - ➢ PFA performance
  - ➢ Rejection of slow neutron events



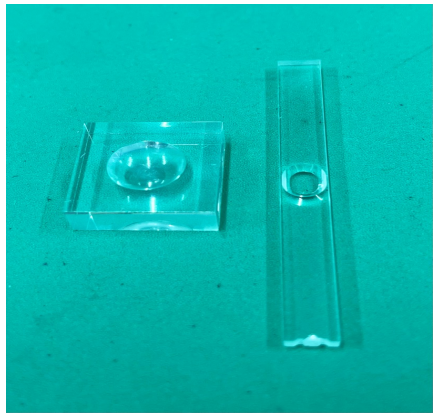
TOF50 = Time of Flight with 50ps resolution

Time resolution of scintillator+SiPM unit is being studied.

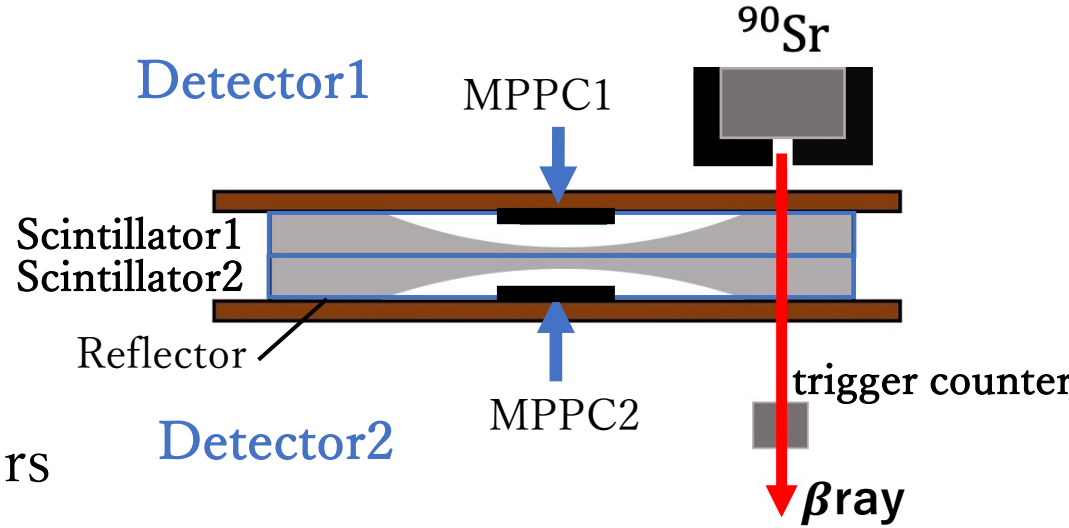
How to measure time resolution



SiPM (MPPC)



Scintillator cell (tile or strip)

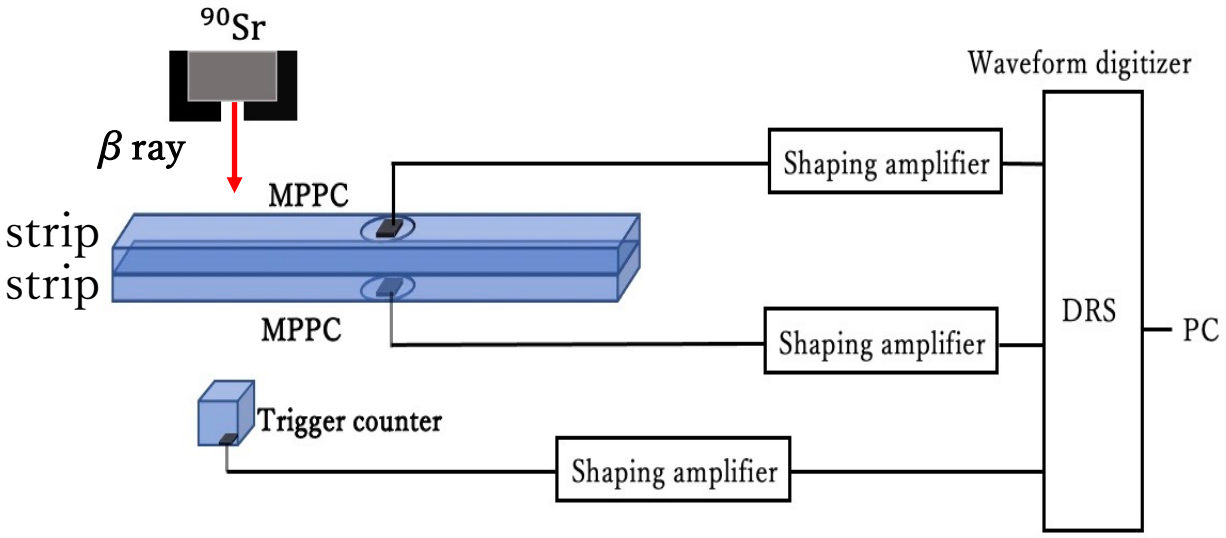


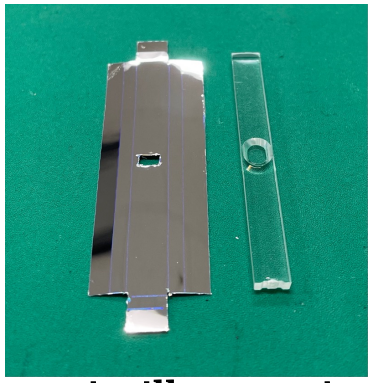
- Time measurement with two identical detectors irradiated by β from Sr-90
- Calculate time resolution from time difference distribution between two detectors.

$$\sigma(T_{MPPC1}) = \sigma(T_{MPPC2}) = \boxed{\boldsymbol{\sigma(T_{MPPC1} - T_{MPPC2})/\sqrt{2}}}$$

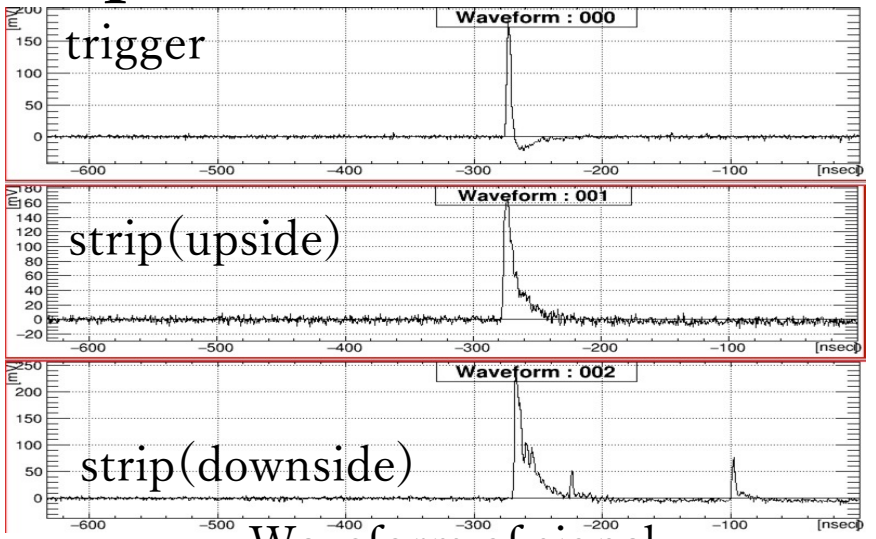
Assuming the time resolution of two scintillator cell (strip or tile) is the same

Time resolution of strip



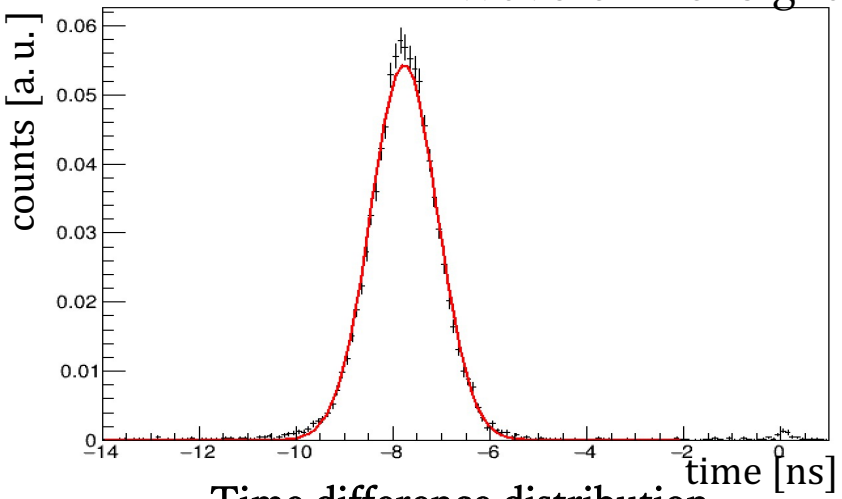


scintillator strip



Waveform of signal

- Scintillator strip : PS scintillator produced by injection molding
  (45mm×5mm×2mm)
- SiPM : MPPC, S12571-015P
  15μm pitch, 1.0mm×1.0mm
- Waveform digitizer : DRS4
  - Time pickup : constant fraction (10%)



Time difference distribution

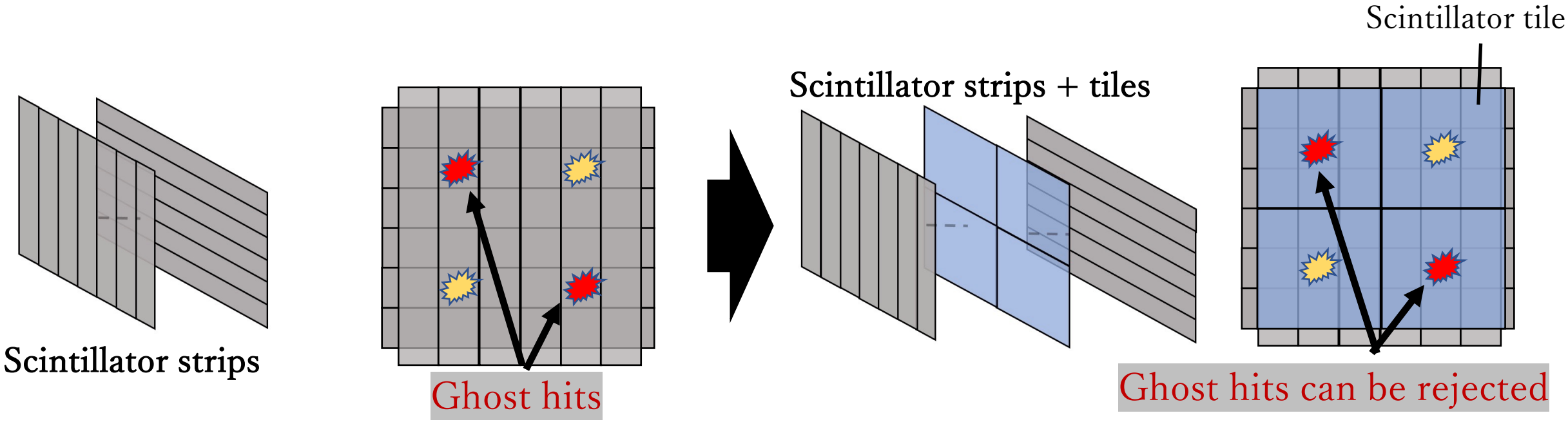
Time resolution ~ 400ps

Not good resolution

Low light yield (20 p.e.)

Dedicated timing layer

- Dedicated timing layer
  - ➢ Scintillator tile and larger SiPM → higher light yield → better time resolution
  - ➢ Arranged at forefront of Sc-ECAL or interleaved between strip layers
- Tile layers interleaved between strip layers would mitigate ghost hit issue.

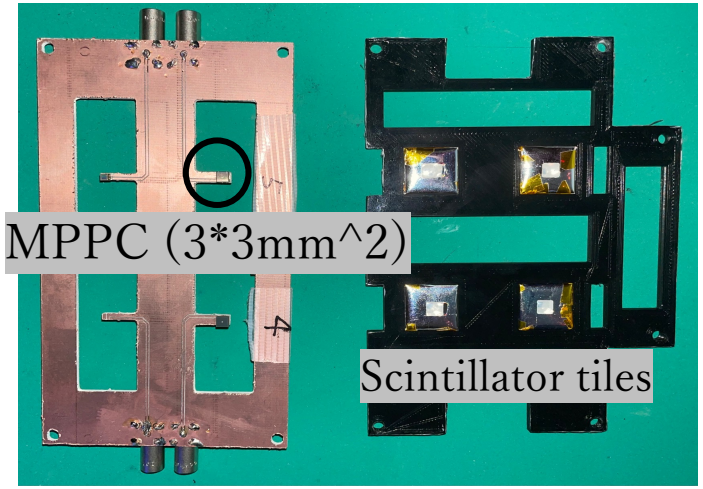


Time resolution of tile

- Studied time performance of scintillator tile with larger SiPM

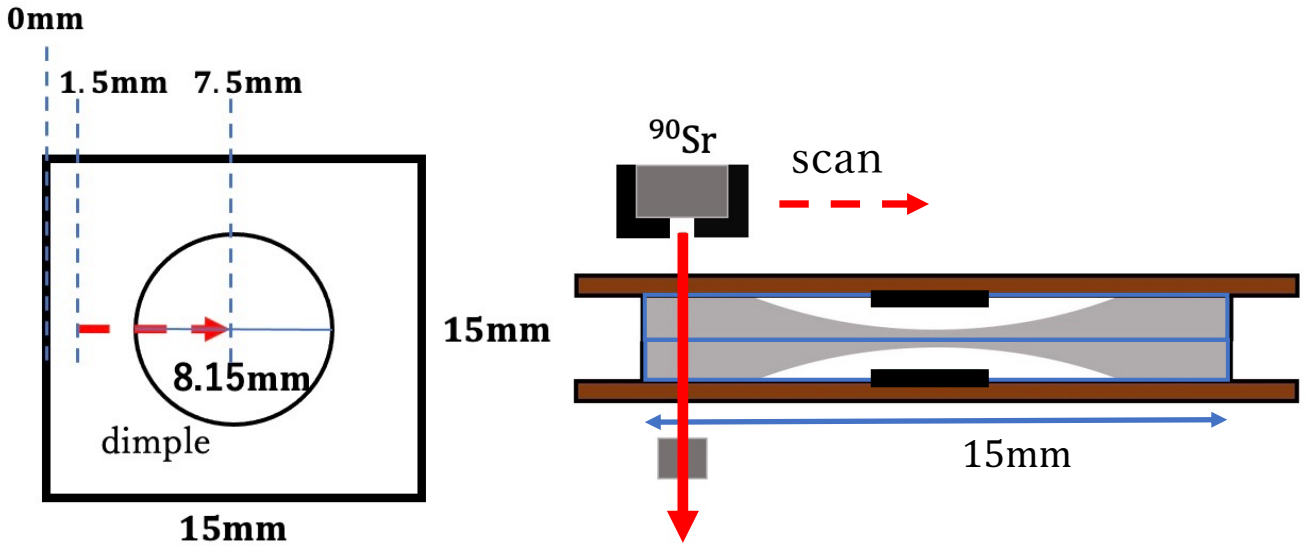
Scintillator tile

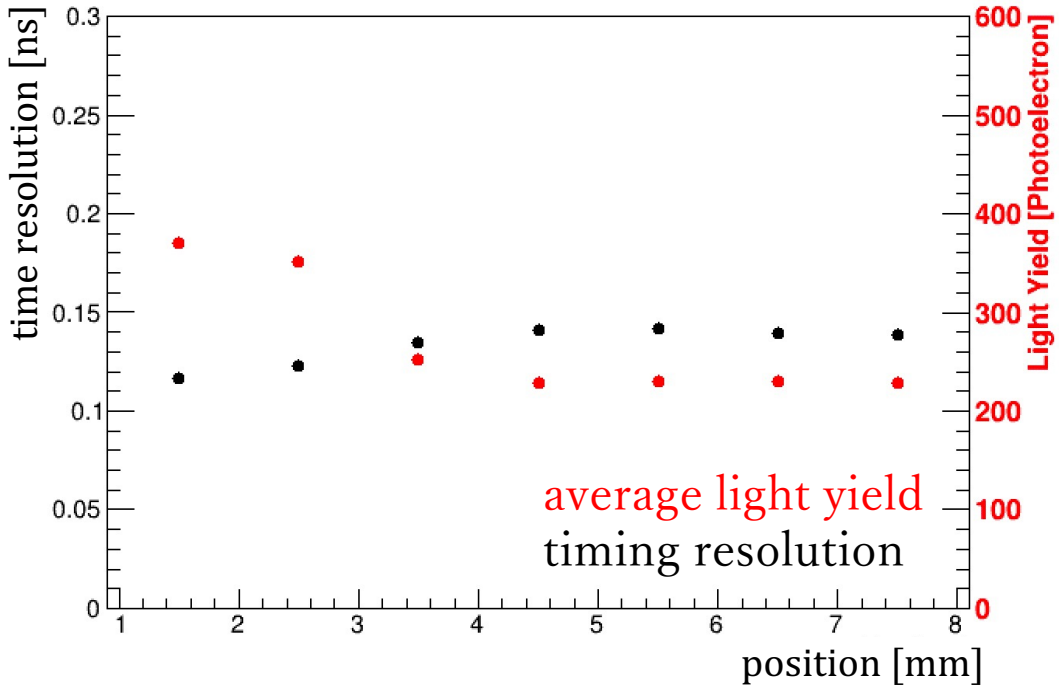
  - Scintillator tile
    - EJ200 (rise time : 0.9ns)
      (15mm×15mm×3mm)
  - SiPM
    - MPPC, S14160-3050HS : 50μm pitch, 3.0mm×3.0mm



Position dependence of time resolution

- Light yield and time resolution were measured at different positions on tile.
- Dimple shape is not optimized yet.



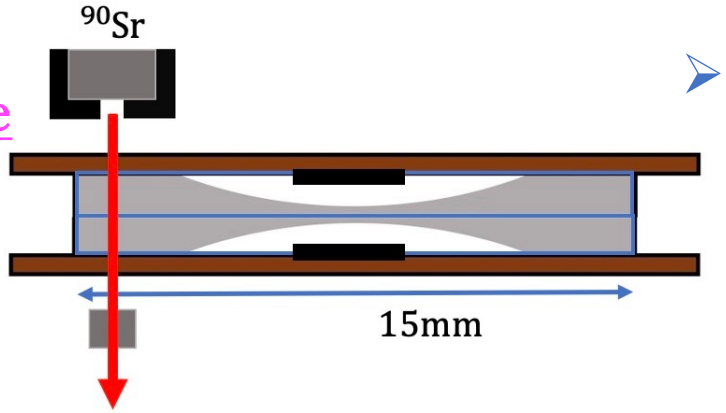


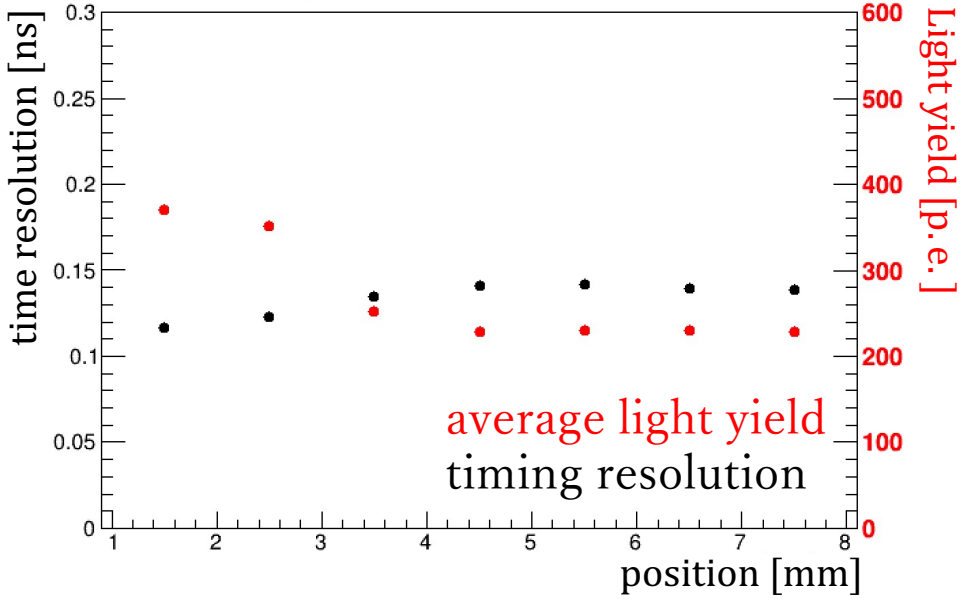
- Time resolution : 117 ps – 142 ps
- Correlated with light yield

Effect of scintillator-SiPM coupling

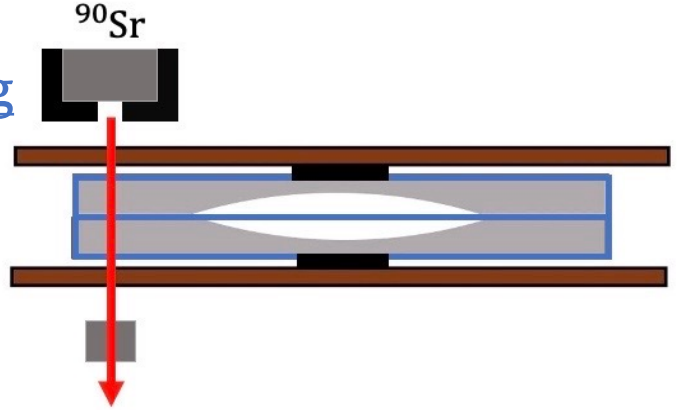
- Effect of the optical coupling with dimple was studied.

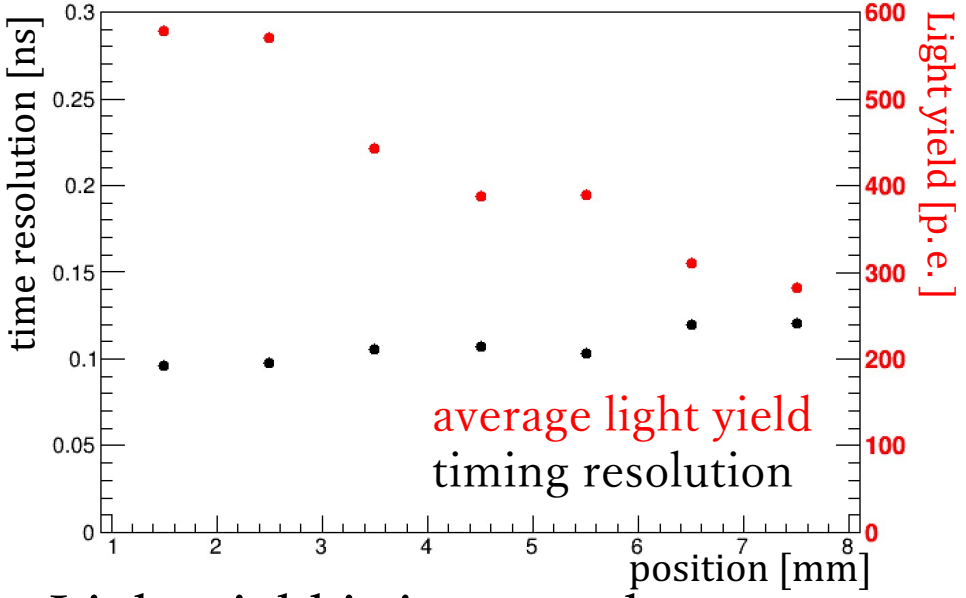
➢ Coupling with dimple





➢ Direct coupling



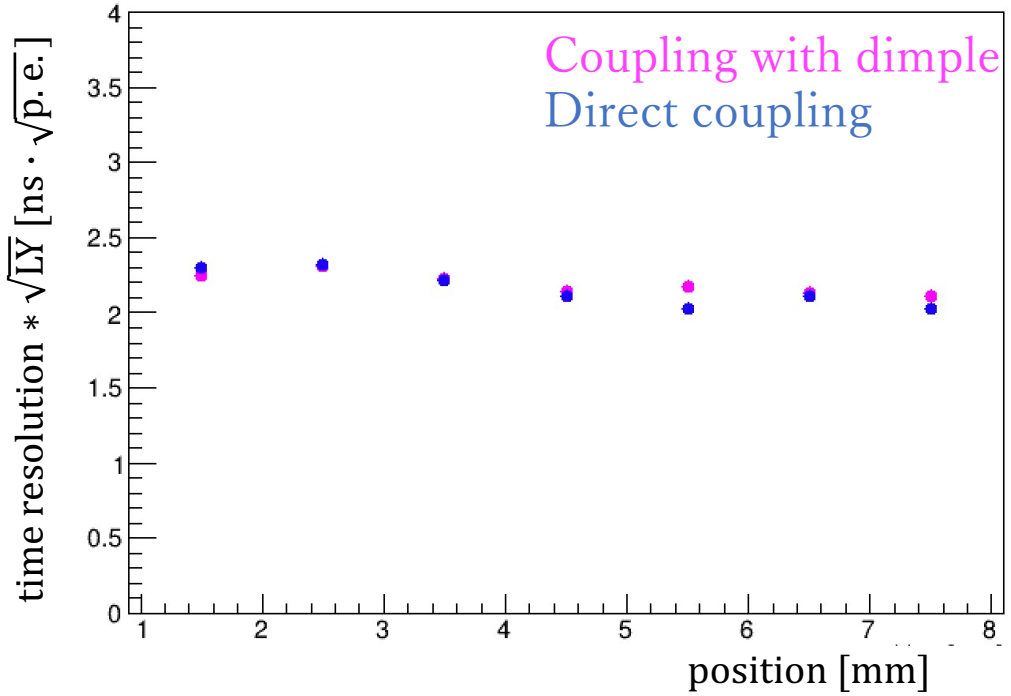


- Light yield is increased
- Time resolution is improved accordingly

Effect of scintillator-SiPM coupling

- Coupling with dimple and Direct coupling were compared by normalizing with photoelectron statistics.

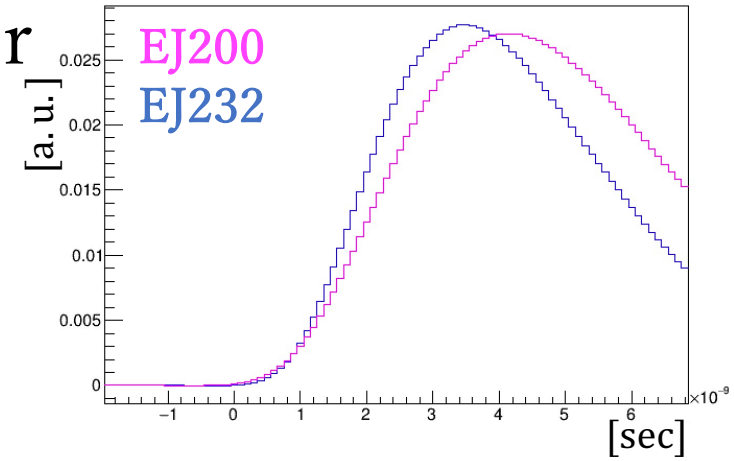
$$Time\ resolution * \sqrt{Light\ yield}$$



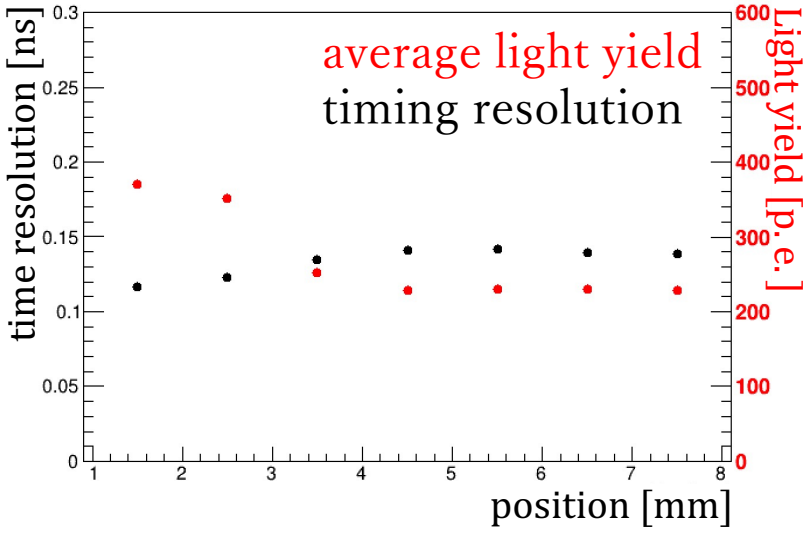
➢ Difference in time resolution is consistent with difference in photoelectron statistics

Time resolution with faster scintillator

- Similar position scan was performed on EJ232
  - EJ200 → rise time : 0.9 ns （catalog）
  - EJ232 → rise time : 350 ps（catalog）

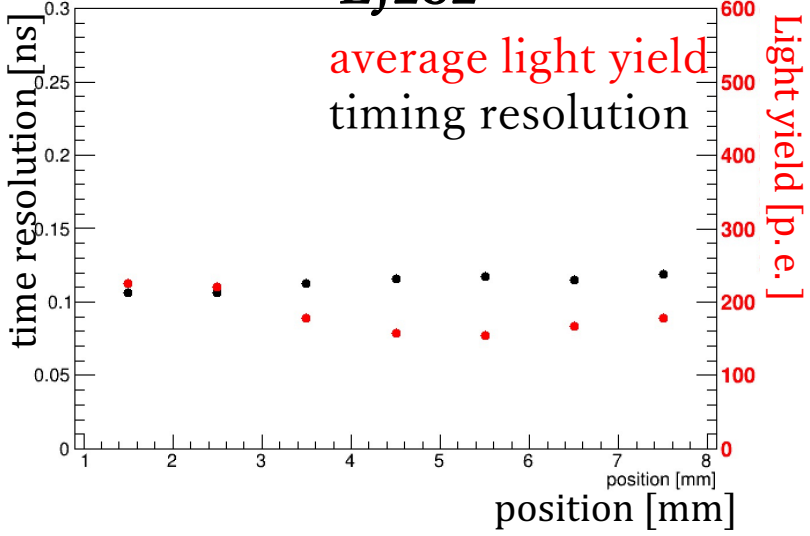


EJ200

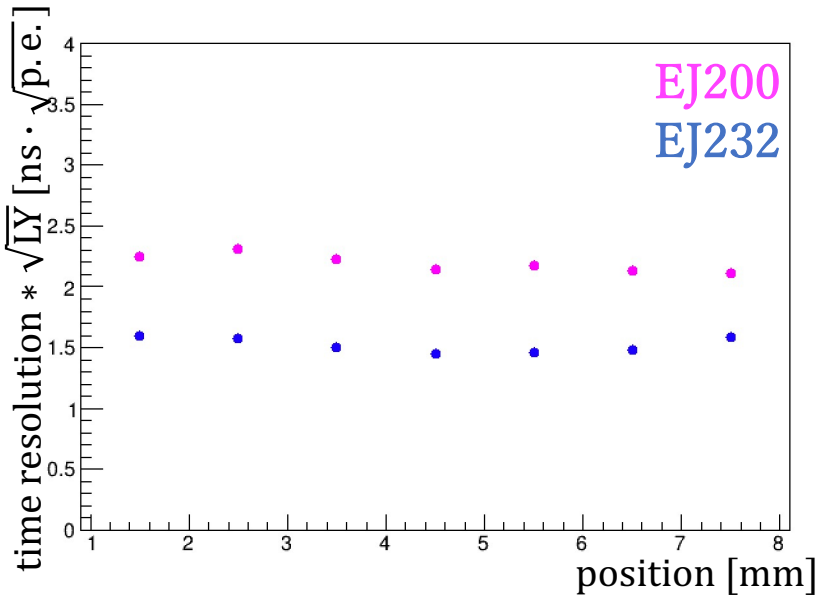


Time resolution : 117 ps – 142 ps

EJ232



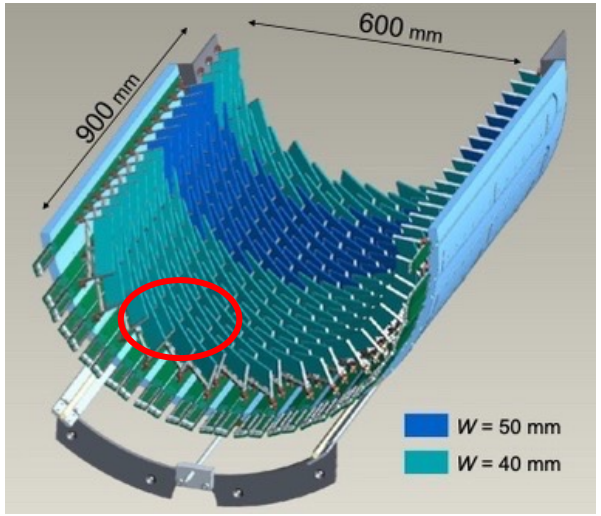
Time resolution : 104 ps – 125 ps



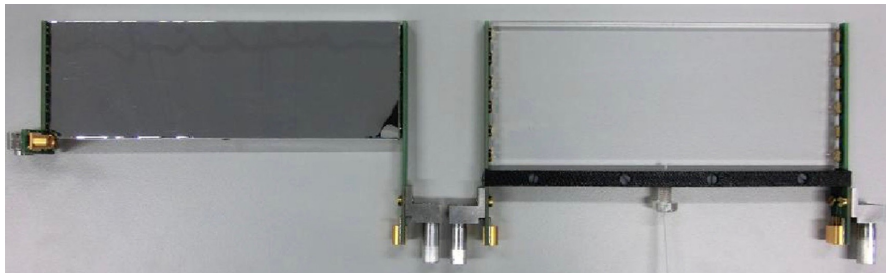
In EJ232, Light yield is lower, but time resolution is even better because of shorter rise time

Comparison with timing counter in MEG II experiment

- **<u>Timing counter (TC) :</u> Signals are measured by 12 SiPMs(6 SiPMs are connected in series)**
  - Scintillator : BC422 (equivalent to EJ232) ,120mm×40(or 50)mm×5mm
  - SiPM : ASD-NUV3S-P : 50μm pitch, 3mm×3mm (similar to MPPC used in this study)
  - The same readout electronics



The design of TC


Counter module

→ Average light yield ~ **100 photoelectron**,
Time resolution : **70ps – 80ps**

If time resolution scales as $1/\sqrt{light\ yield}$,
time resolution for tile in this study (LY~200 p.e.)
is expected to be 50-60ps.

↔measured time resolution :104ps

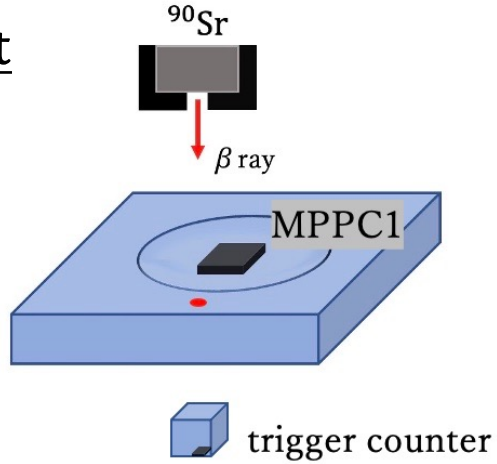
Difference is not understood yet

https://arxiv.org/abs/1801.04688

Comparison of readout scheme

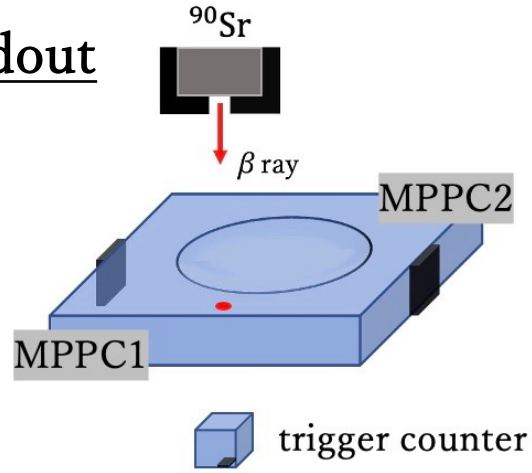
- The difference in time resolution between dimple readout and double-side readout (as in MEG II) was tested.
  - Scintillator tile : EJ232 (15mm×15mm×3mm)
  - MPPC, S14160-3050HS : 50μm pitch, 3mm×3mm

➢ <u>dimple readout</u>



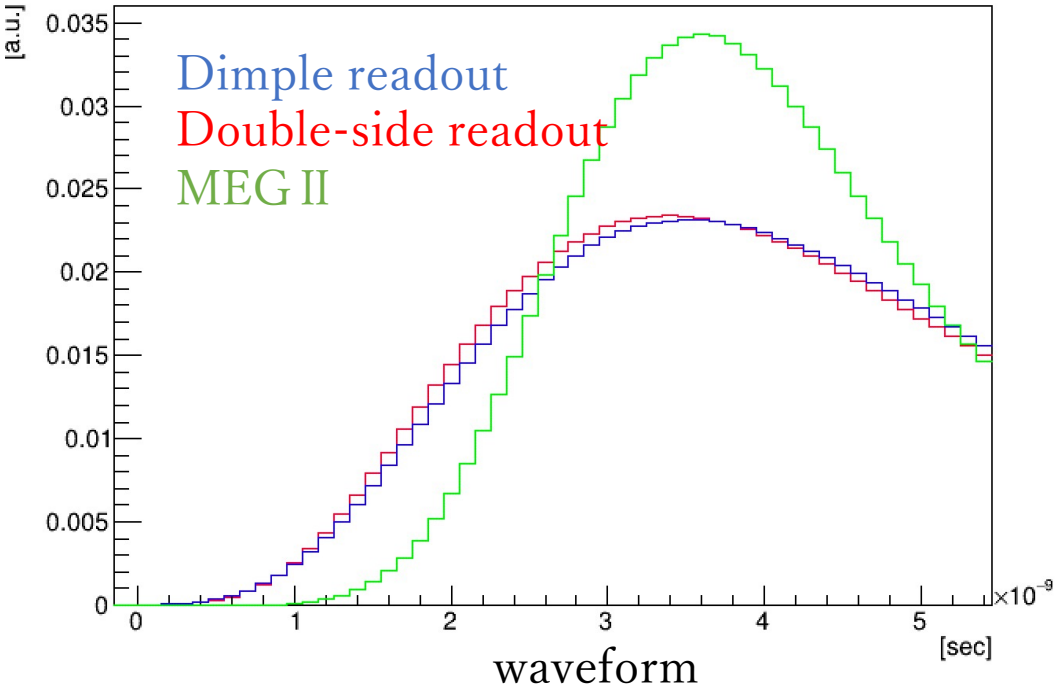
- rise time : 1.7 ns
- Light yield : 201 p.e.
- $\sigma(T_{MPPC1} - T_{trigger}) \ominus \sigma(T_{trigger}) = 112\text{ps}$

➢ <u>double-side readout</u>



- rise time : 1.7 ns
- Light yield : 211 p.e.
- $\sigma(\frac{T_{MPPC1}+T_{MPPC2}}{2} - T_{trigger}) \ominus \sigma(T_{trigger}) = 87\text{ps}$

Summary of comparison



	Dimple readout	Double-side readout	MEG II
rise time (10 to 90%)	1.7ns	1.7ns	1.2ns
S/N	89	82	103
Light yield	~200 p. e.	211 p. e.	~100 p. e.
time resolution	104 − 125 ps	87 ps	~80 ps
time res $*\sqrt{\text{LY}}$ $[\text{ns}\cdot\sqrt{\text{p. e.}}]$	~1.6	1.3	~0.8

Possible reasons for the worse resolution compared to MEG II

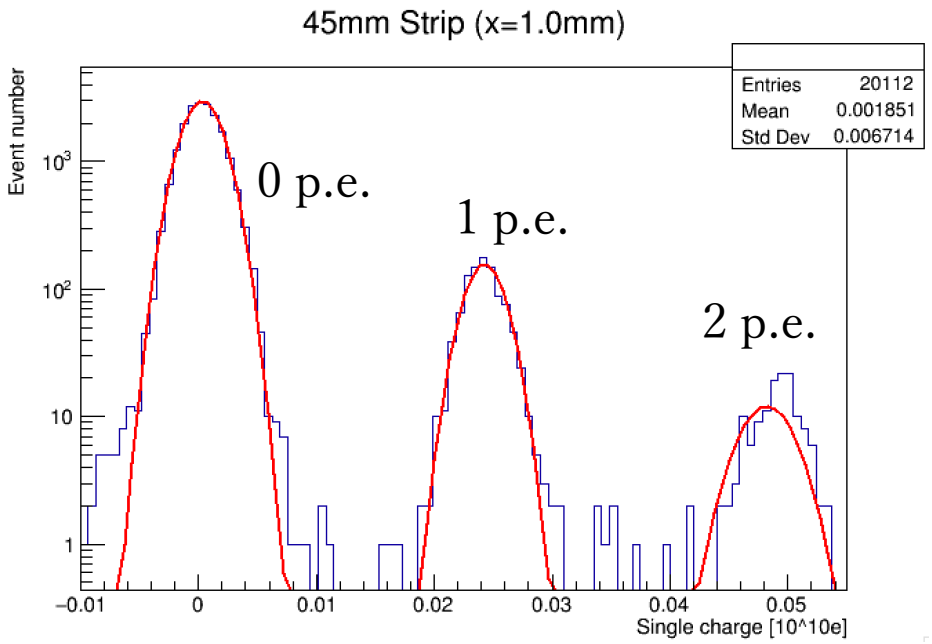
- Slower rise time
  - Difference in scintillator quality? Effect of series connection?
- Lower S/N
- Difference in readout scheme (single SiPM, multiple SiPM readout, mutiple SiPM connected in series) ➡ No clear understanding yet

Summary

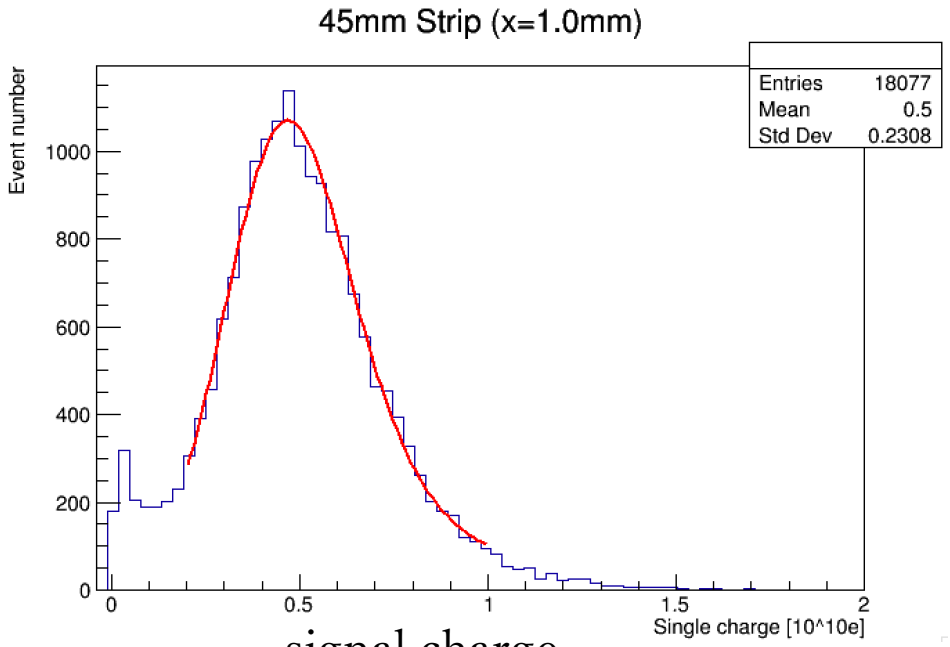
- Time resolution for scintillator-SiPM unit Sc-ECAL was studied.
- Better time resolution for tile compared to strip because of higher light yield
  (strip : ~400 ps , tile : > 117 ps (EJ200))
- Better time resolution for EJ232 compared to EJ200 because of faster rise time.
- Target resolution ~50ps according to our experience in MEG II timing counter
  - Worse time resolution compared to MEG II timing counter despite the similar setup. (MEG II : ~70 – 80 ps , This measurement : ~104 ps)
  - The detailed comparison is still in progress to understand the difference.

Backup

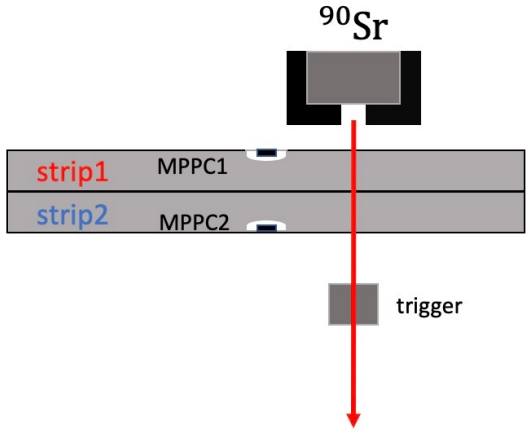
Gain & light yield in strip measurement



dark noise distribution



signal charge



Average Light yield = charge/gain

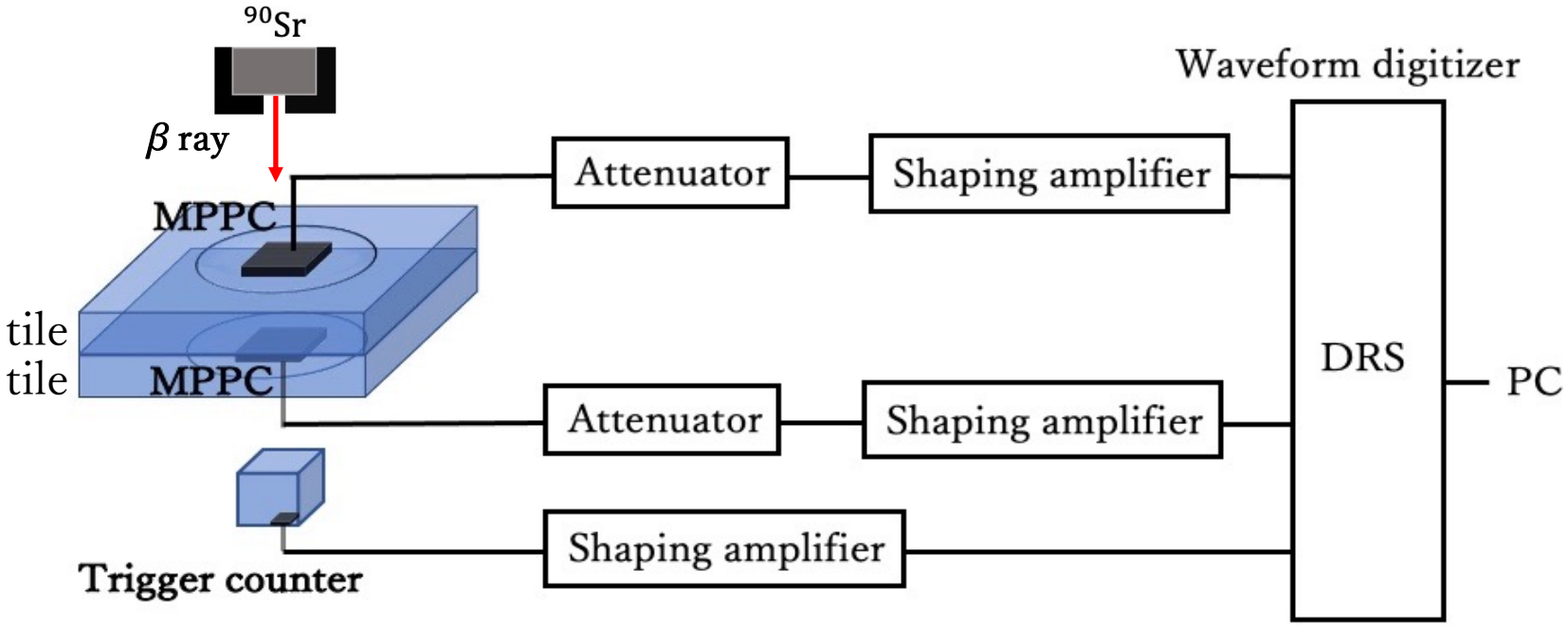
⬇

strip1 : 20.5 photoelectron

strip2 : 19.6 photoelectron

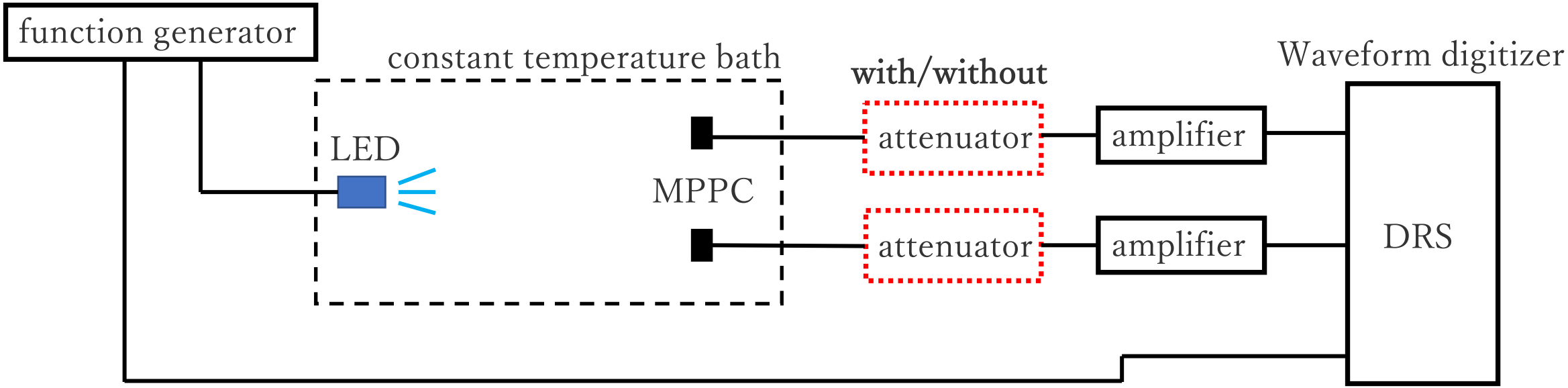
Gain & light yield in tile measurement

- Setup of tile measurement



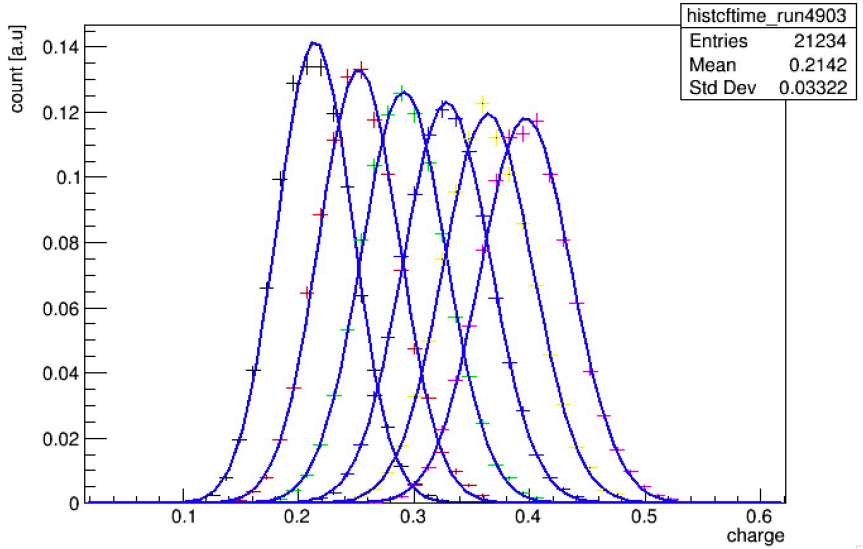
Gain & light yield in tile measurement

setup

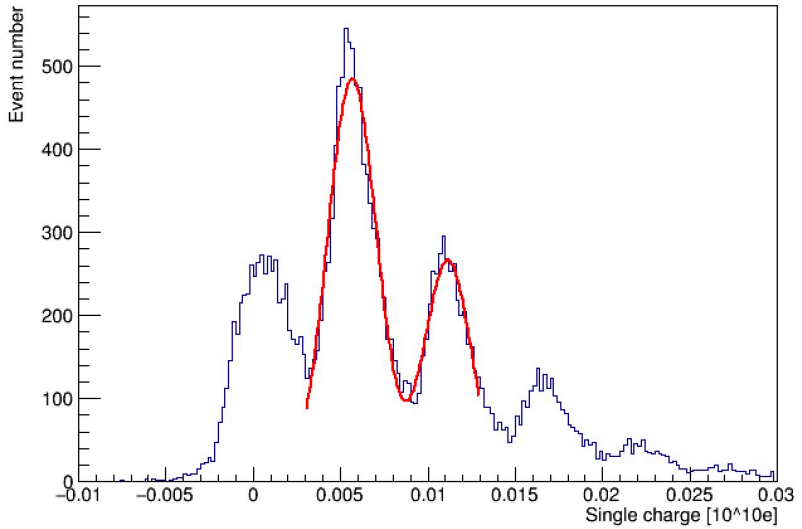


- Expose MPPC to the LED light with the same light yield ,with / without attenuator.
- Convert the light yield calculated using the gain without attenuator to the gain with attenuator.

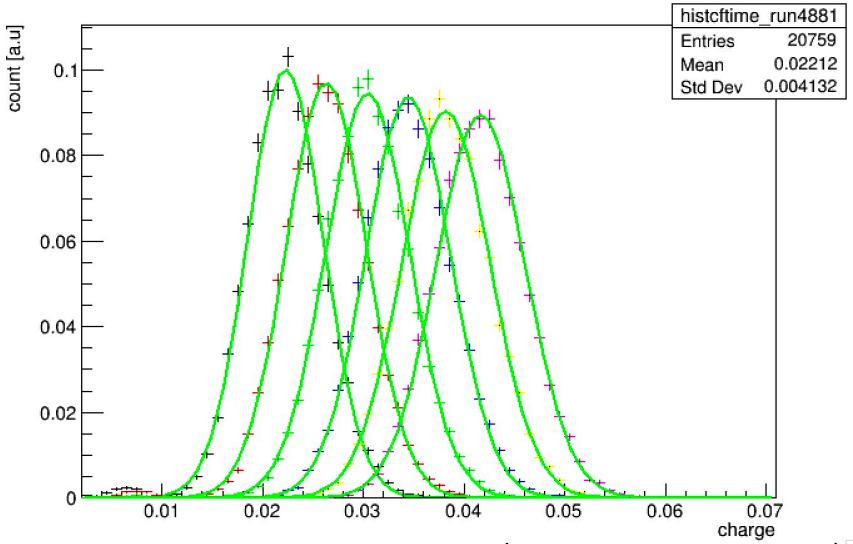
Gain & light yield in tile measurement



charge distribution (without attenuator)

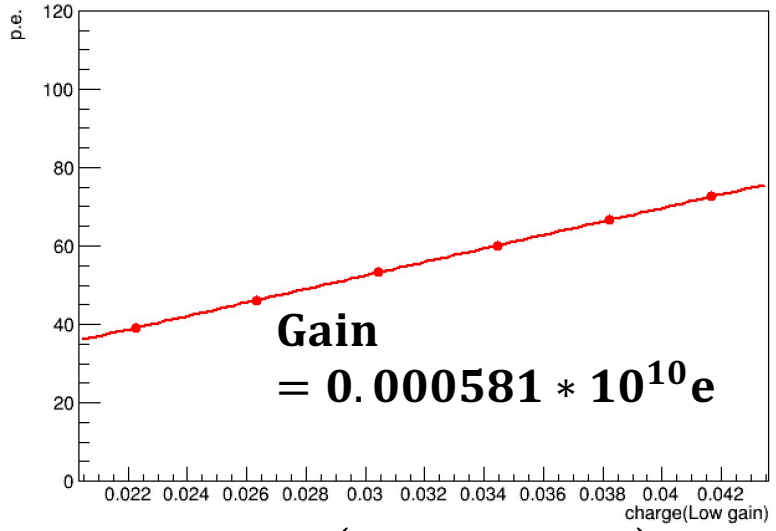


Low charge distribution → obtained gain (without attenuator)



charge distribution (with attenuator)

Light yield of LED

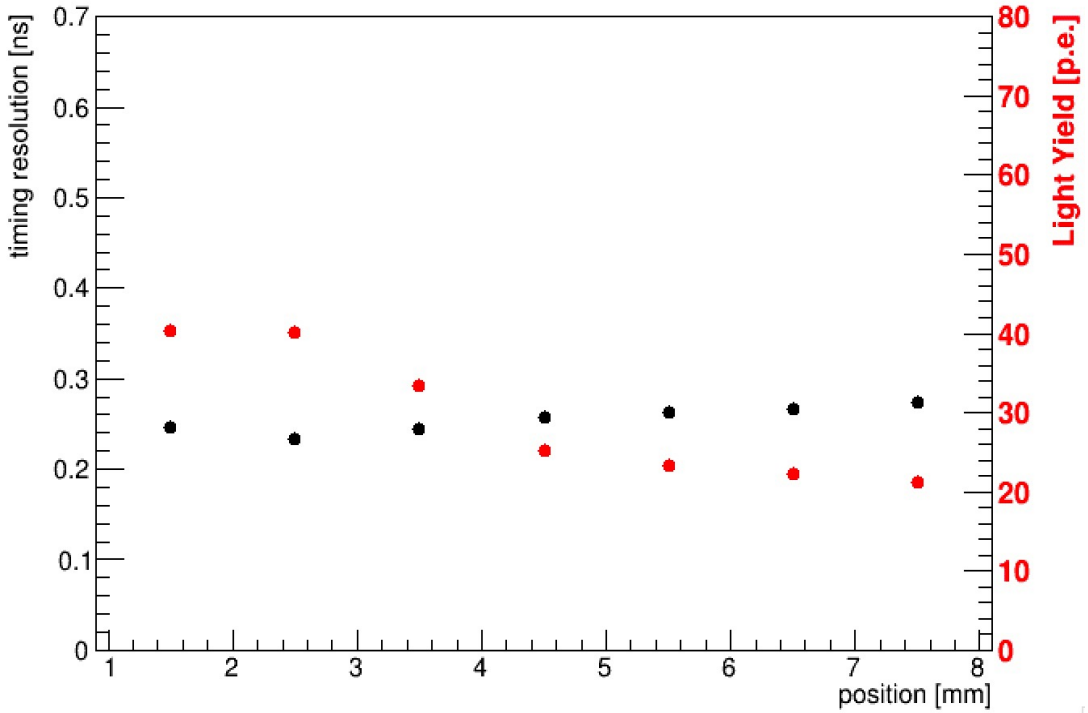


charge (with attenuator)

Time resolution measured with 1.3mm square MPPC

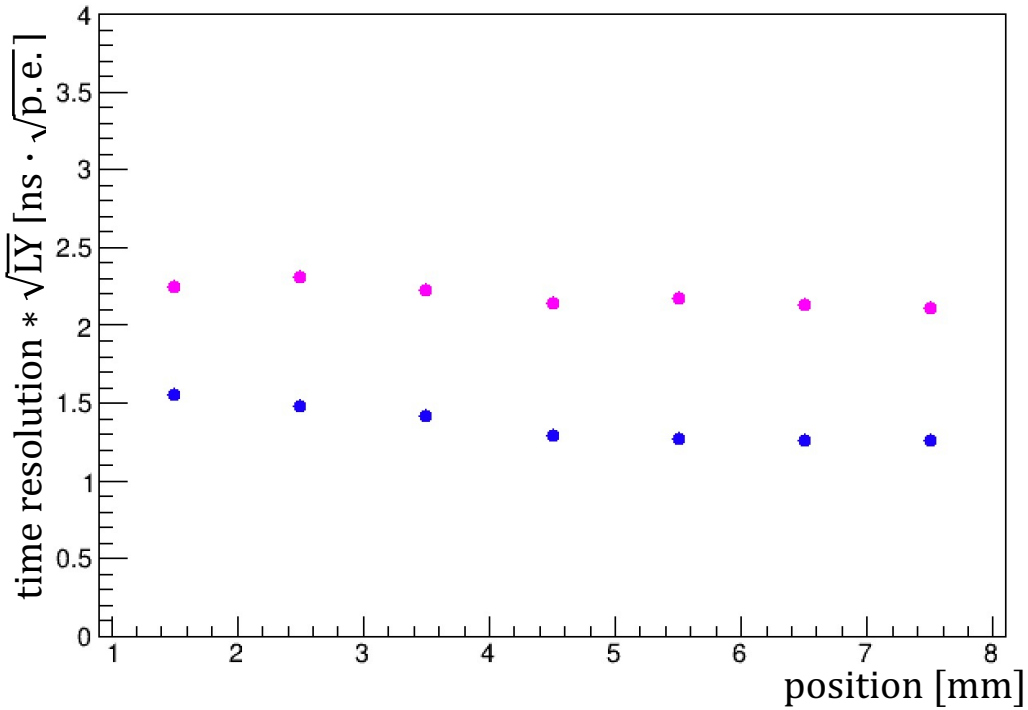
- Scintillator tile : EJ200
- SiPM : MPPC S14160-1315PS

- average light yield
- timing resolution



Time resolution & light yield of **EJ200**

- 3mm square , 50μm pitch MPPC
- 1.3mm square , 15μm pitch MPPC



Timing resolution * $\sqrt{\text{Light yield}}$ at each positions