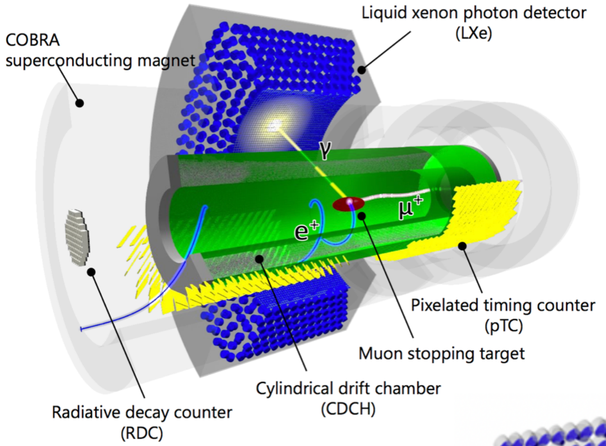
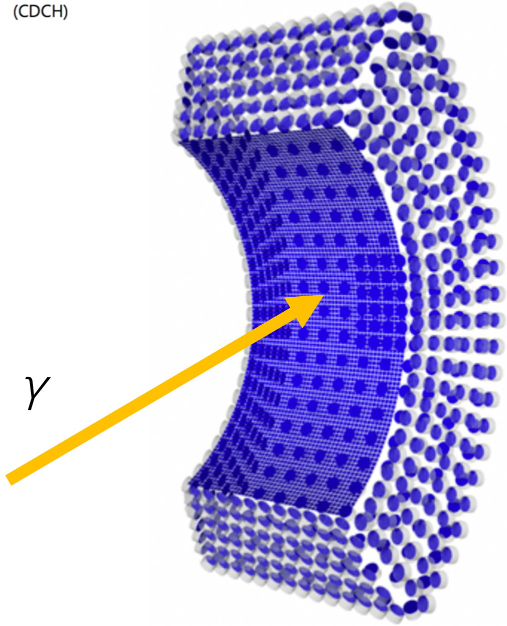
Development of pre-shower counter for time calibration of MEG II liquid xenon detector

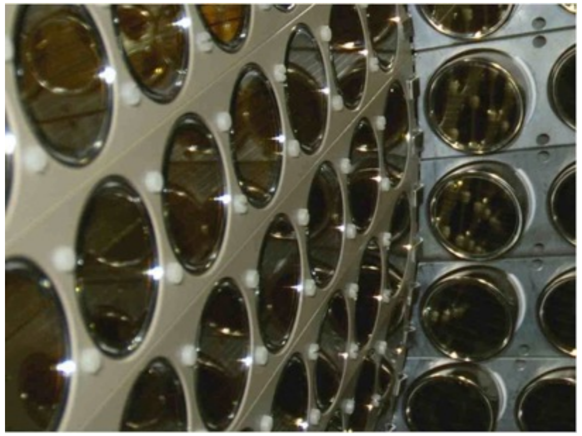
Rina Onda
On behalf of MEG II collaboration
The University of Tokyo

Liquid Xenon Detector

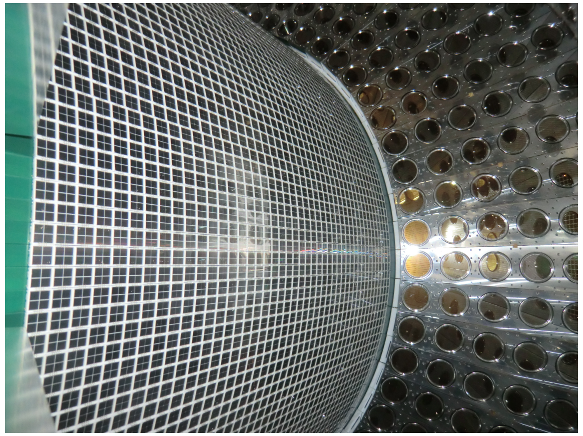




MEG



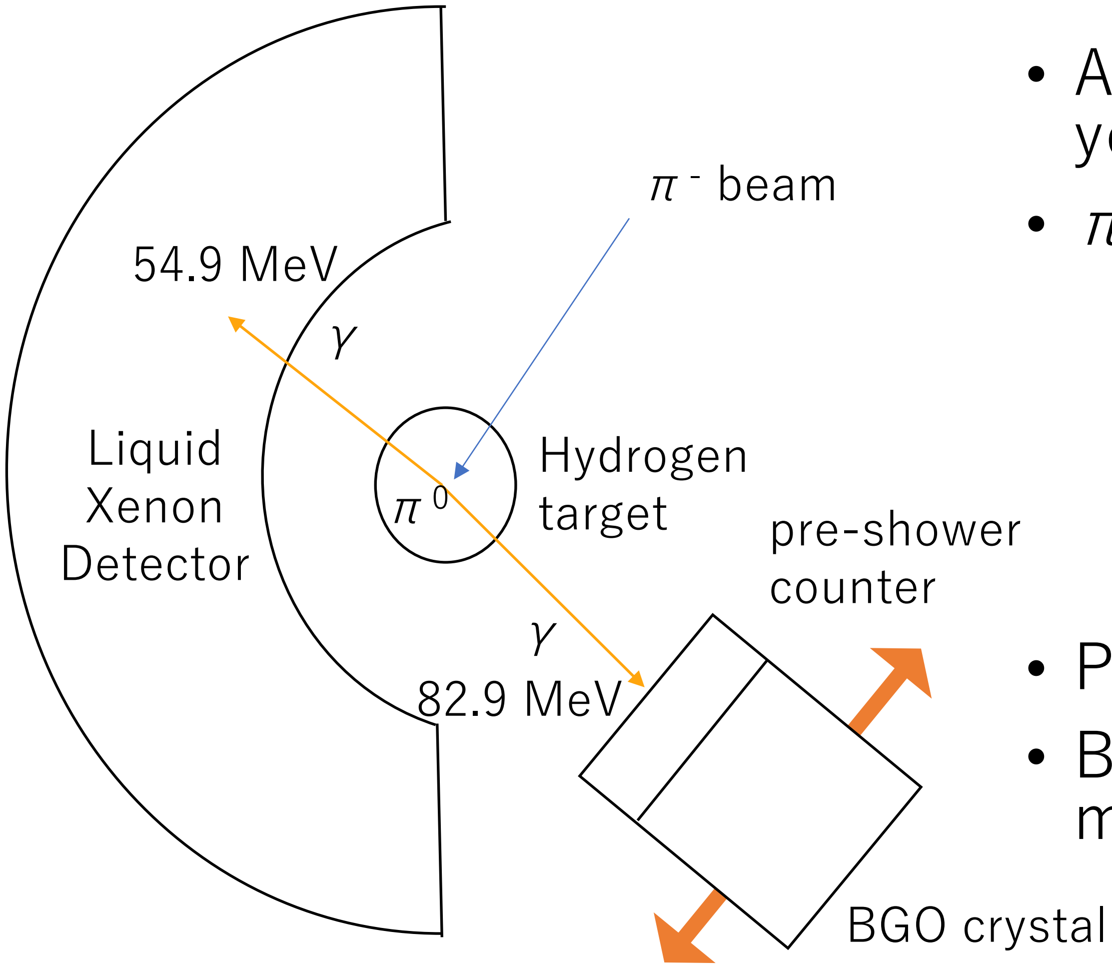
MEG II



- Detects γ energy, position and timing
- Liquid xenon scintillator and photon sensors
- Replaced 216 PMTs with 4092 MPPCs
  time resolution 67 ps → 50 ps

25aK206 : In-beam performance of MEG II liquid Xe detector (Shinji Ogawa)

Calibration using Charge EXchange

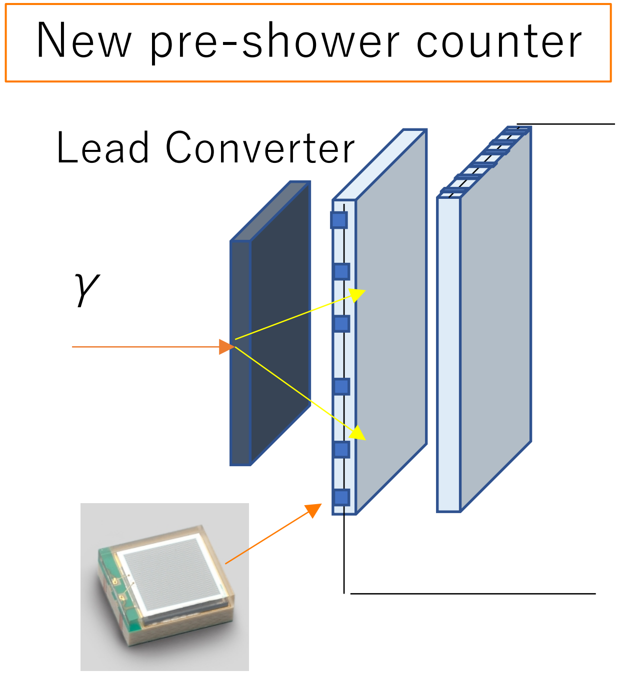


- A calibration run for LXe detector planned this year
- π^0 is produced in

$$\pi^- p \rightarrow \pi^0 n$$

  - Monochromatic energy γ-ray selecting back-to-back event from $\pi^0 \rightarrow \gamma\gamma$
  - Similar energy with signal γ
- Pre-shower counter for a timing measurement
- BGO crystal for energy and position measurements

Pre−shower Counter @MEG II



Pre-shower counter @MEG

- 2 plastic scintillators readout with fine mesh PMTs
- Final time resolution 72 [ps] is worse than that of LXe (50 [ps])

New pre-shower counter

- 2 plastic scintillators readout with SiPMs

Good timing resolution can be achieved like MEG II Timing Counter

MEG II Timing Counter study

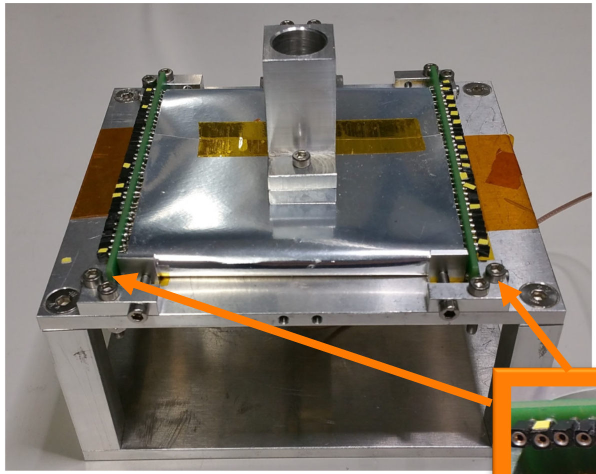
- More light yields → more SiPMs
- Fast risetime → series > parallel connection

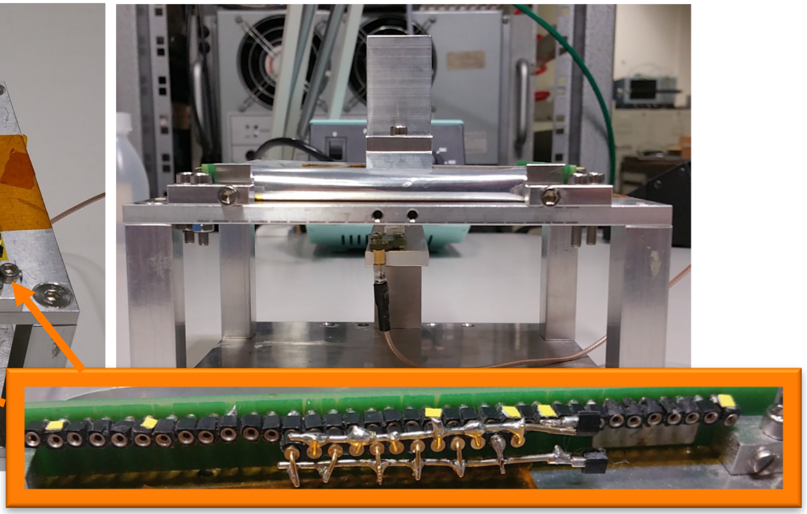
Topics of this talk

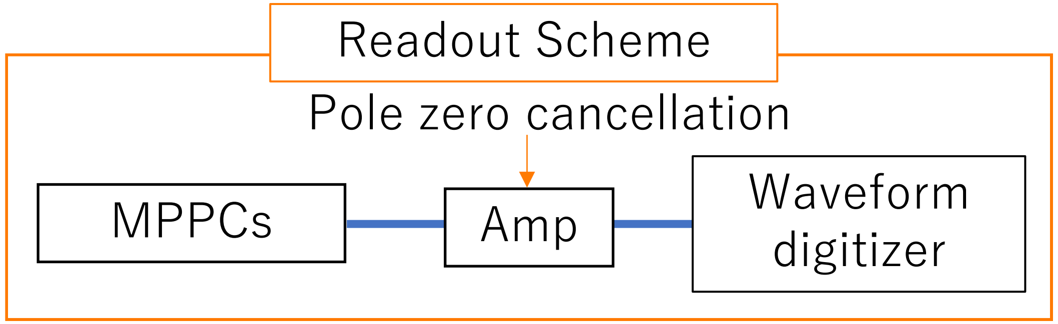
- Investigations to decide the counter design
  - The number of SiPMs and their connection
  - Size and shape of a scintillator

Comparison of SiPM Connection Scheme

Setup to Test SiPM Connections



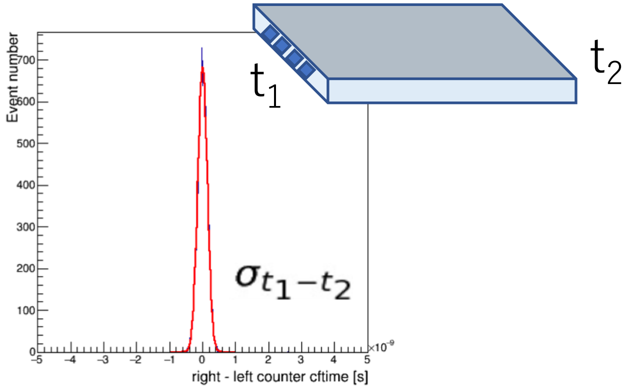




Change the number of MPPCs used or connection

Test counter
- Plastic scintillator : BC420, Saint-Gobain
  - Attenuation length 140 cm
- MPPC : S13360-3050PE, Hamamatsu Photonics
  - 3×3 [mm^2] photosensitive area
  - $V_{br} \sim 52$ [V]
- Reflector : ESR2 (Polyester)
- Optical grease : 6262A, OHYO KOKEN KOGYO CO.

Trigger counter
- Plastic scintillator : BC422 ($5 \times 5 \times 5$mm^3)
- MPPC : S10362-22-050C

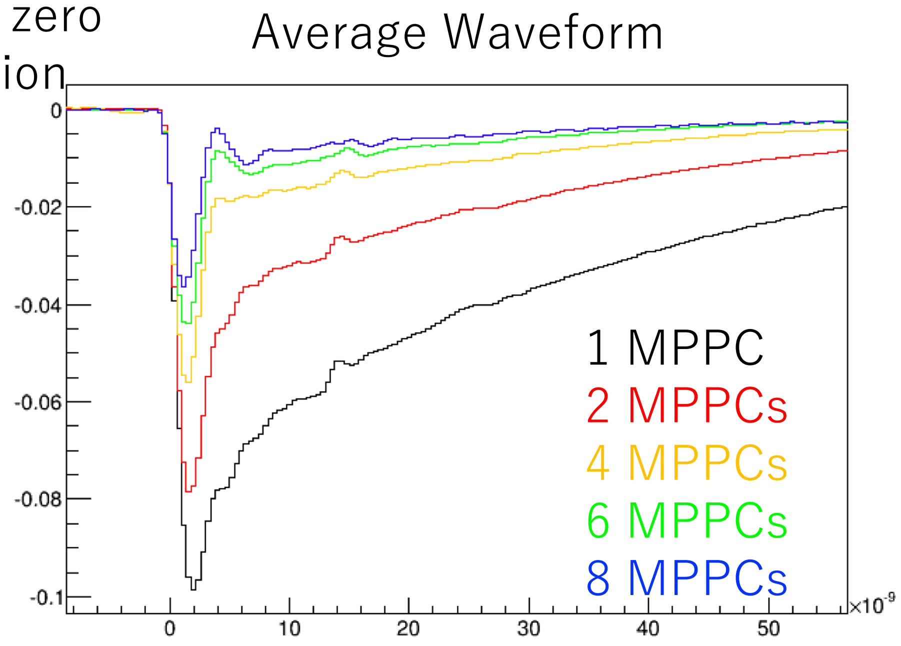


Resolution was calculated by subtracting the time of one side t_1 from the other side t_2

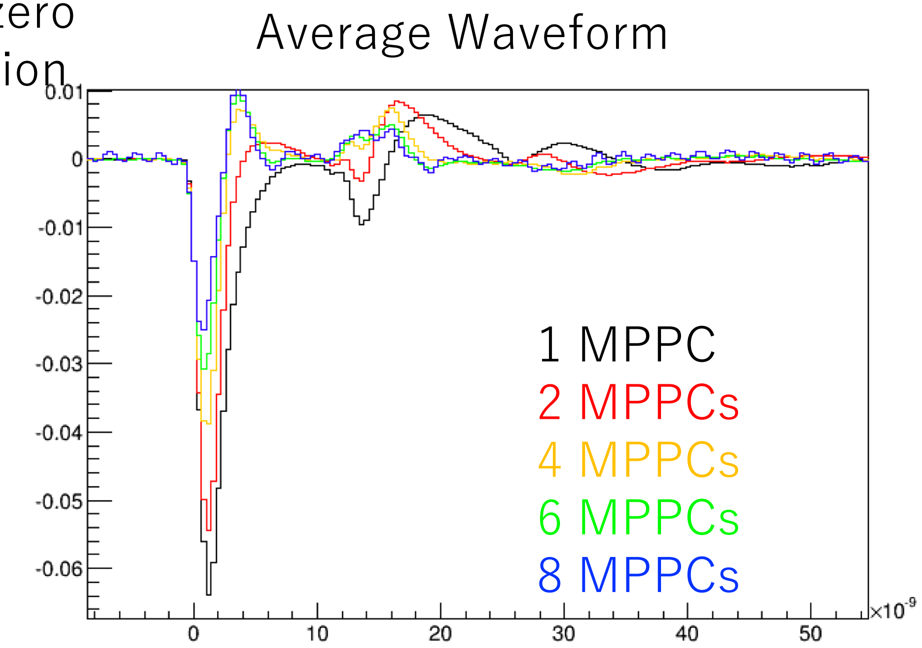
$$\sigma_{counter} = \frac{\sigma_{t_1-t_2}}{2}$$

Difference of Single Photoelectron Waveform Caused by Series Connection

w/o pole zero cancellation



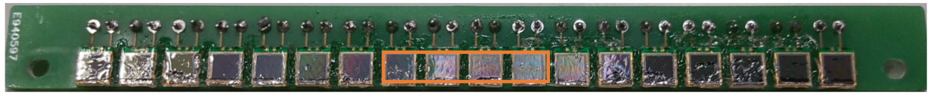
w/ pole zero cancellation

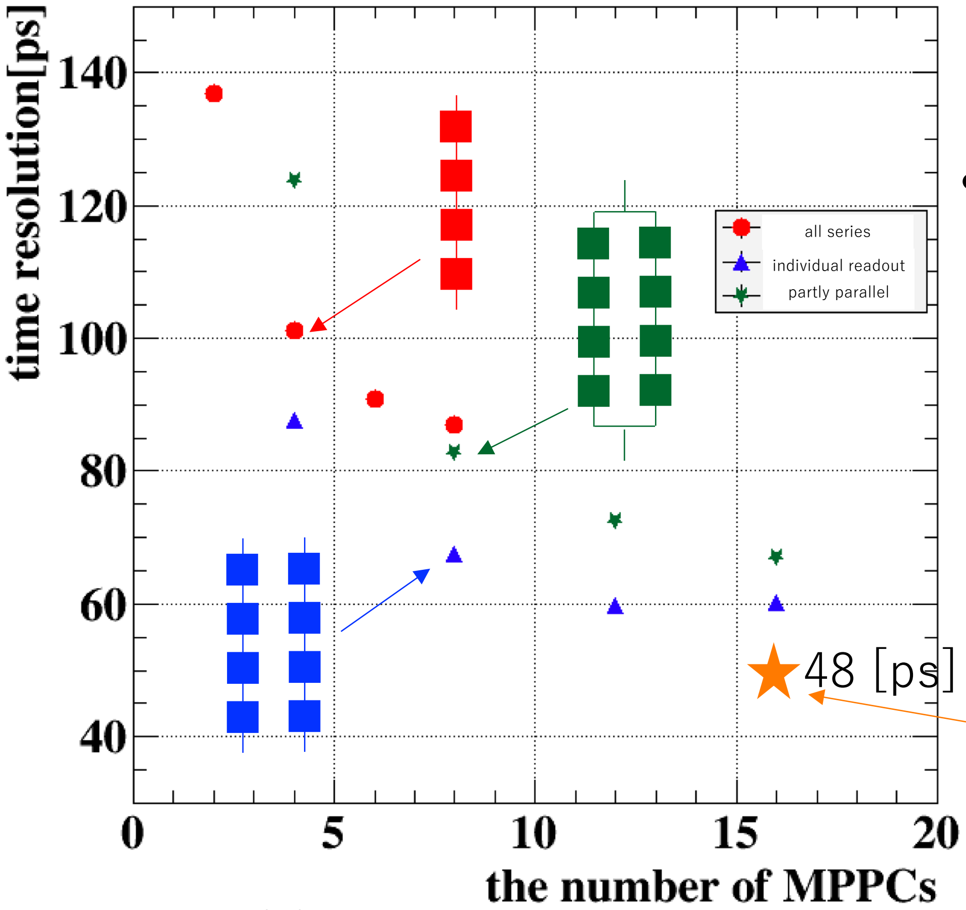


As more MPPCs are connected in series, capacitance gets smaller.

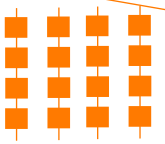
- faster risetime
- height becomes lower
  →S/N is not good when there are too many MPPCs connected in series

MPPC Connection Effect to Time Resolution





- Tested two other connections
  - individual readout : twice capacitance
  - partly parallel : 4 times capacitance
- Measurements show improvement of time resolution starts to saturate when about 4 MPPCs are connected
  →Individual readout and partially parallel connection are better when the number of MPPCs are more than 8

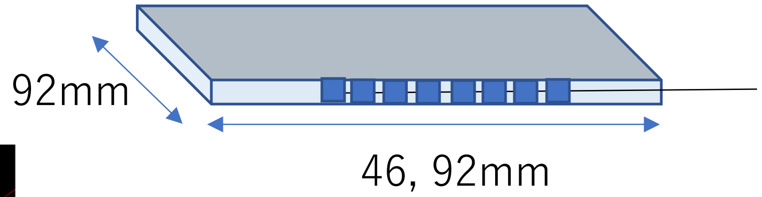


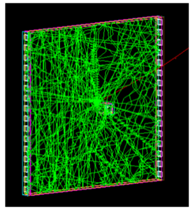
Decided to use 4 series connection

(4 series× 4 readout × 2 sides)

Comparison of different Scintillator Sizes

Comparison of Time Resolution with Different Scintillator Sizes

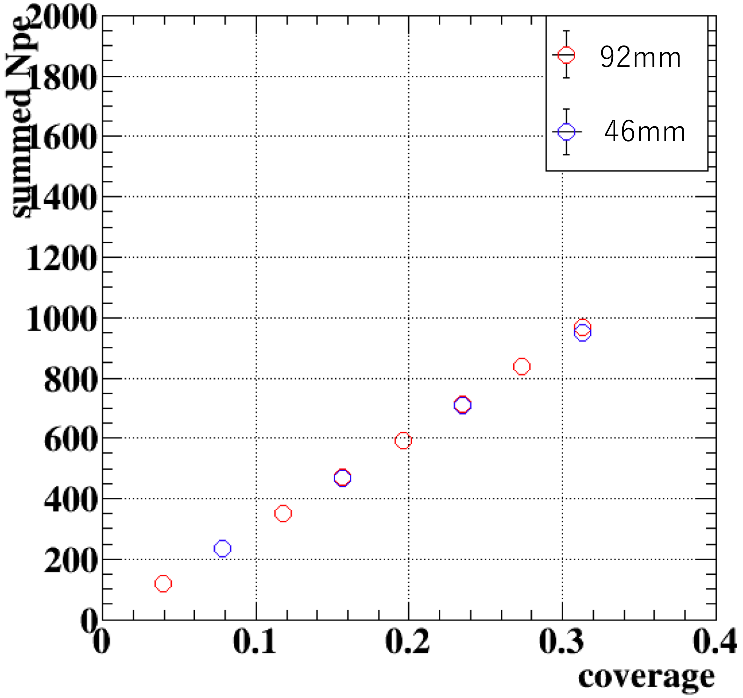




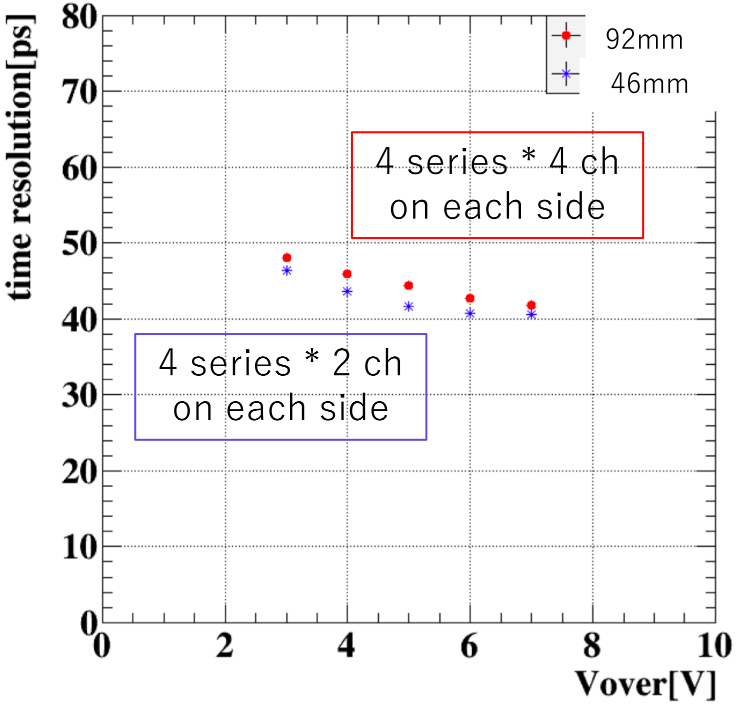
Simulated using Geant4

- Detected light yield is the most important factor to get good time resolution
- According to simulation, light yield of a scintillator doesn't depend on scintillator size but on SiPM coverage
  →Suggests time resolution is the same
- Measurements proved that

Detected Light Yield (simulated)



Time Resolution (measured)

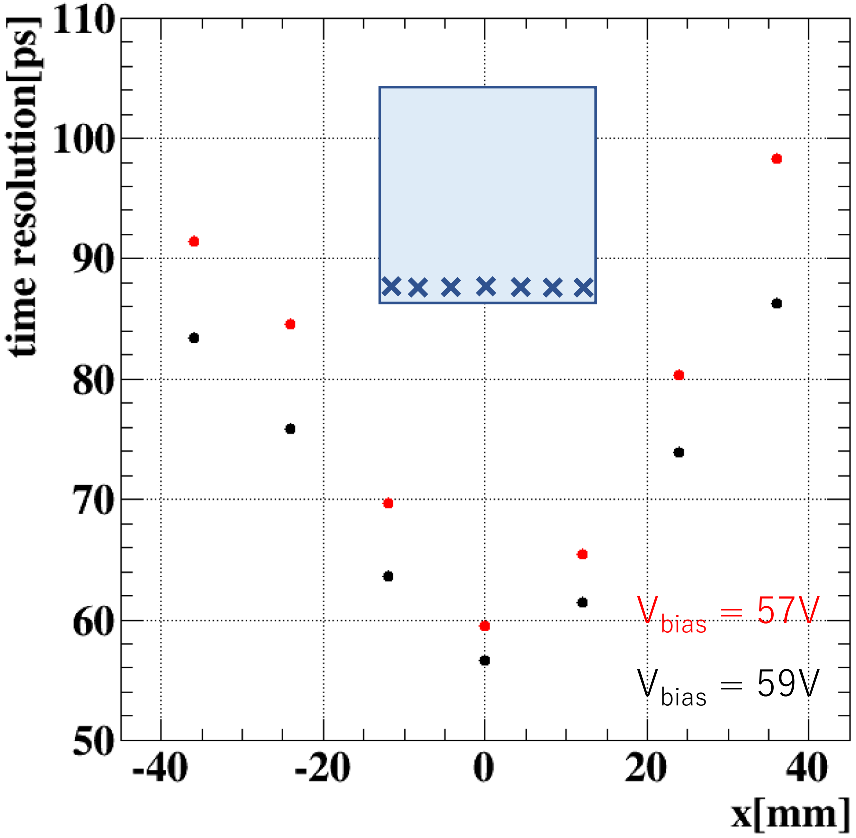


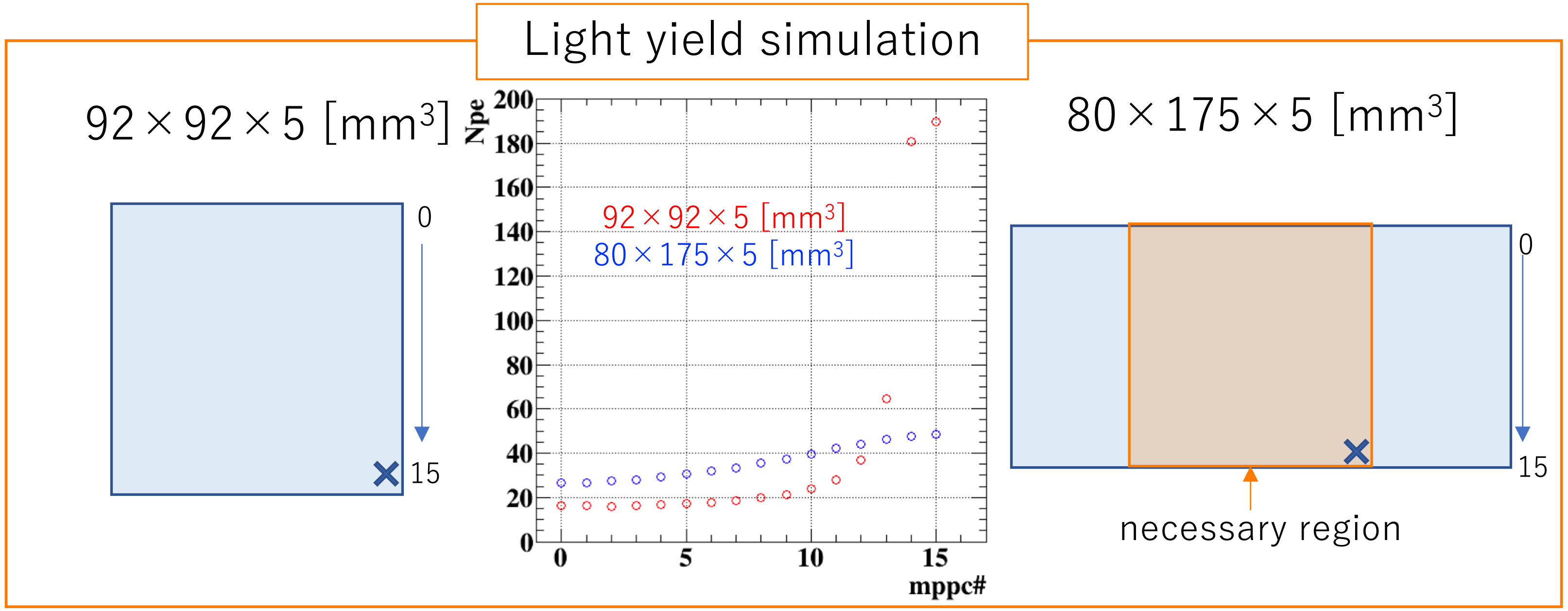
Decided to use 92 [mm] scintillator for larger acceptance

Position Scan

Light Yield Position Dependence

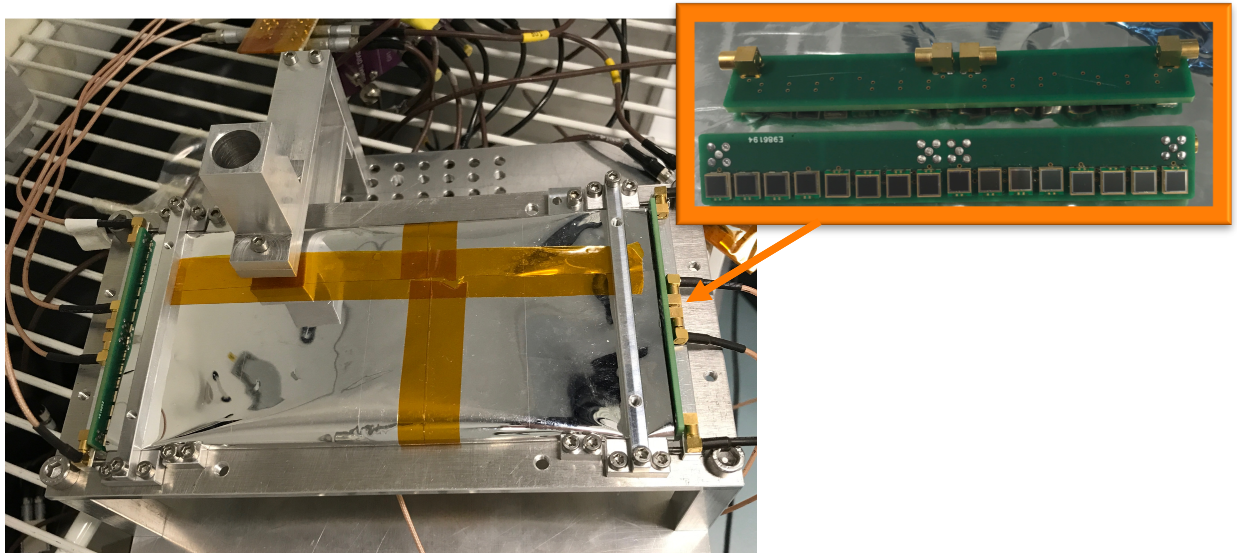
Position Dependence of Time Resolution

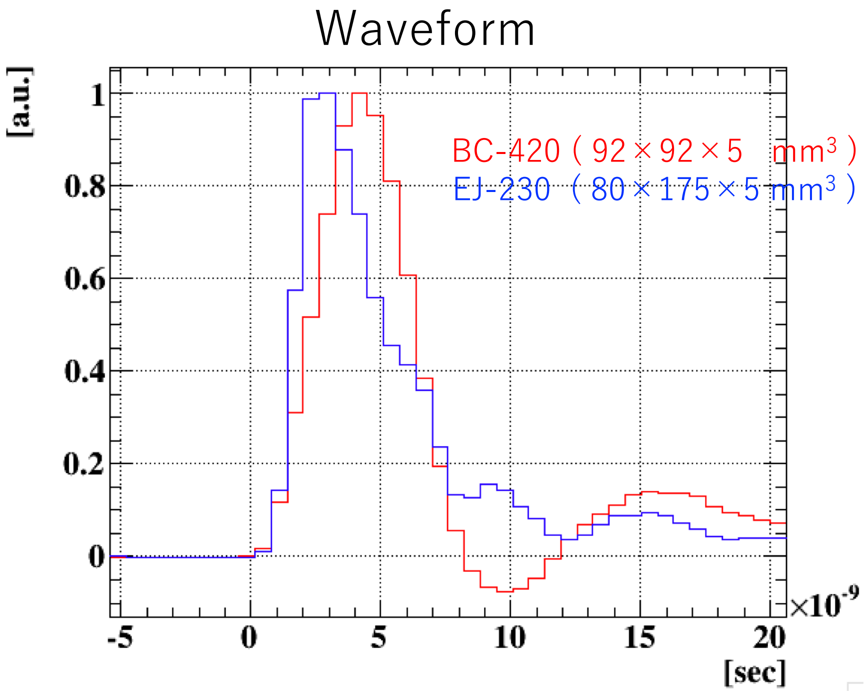




- When RI is far from the center, light yields of some channels are too small while other channels saturate depending on their positions
  →less statistics & worse S/N
  →large position dependence of time resolution
- According to simulations, if the length of scintillator is longer, the light yield difference is less in the necessary region.

Setup for New Scintillator



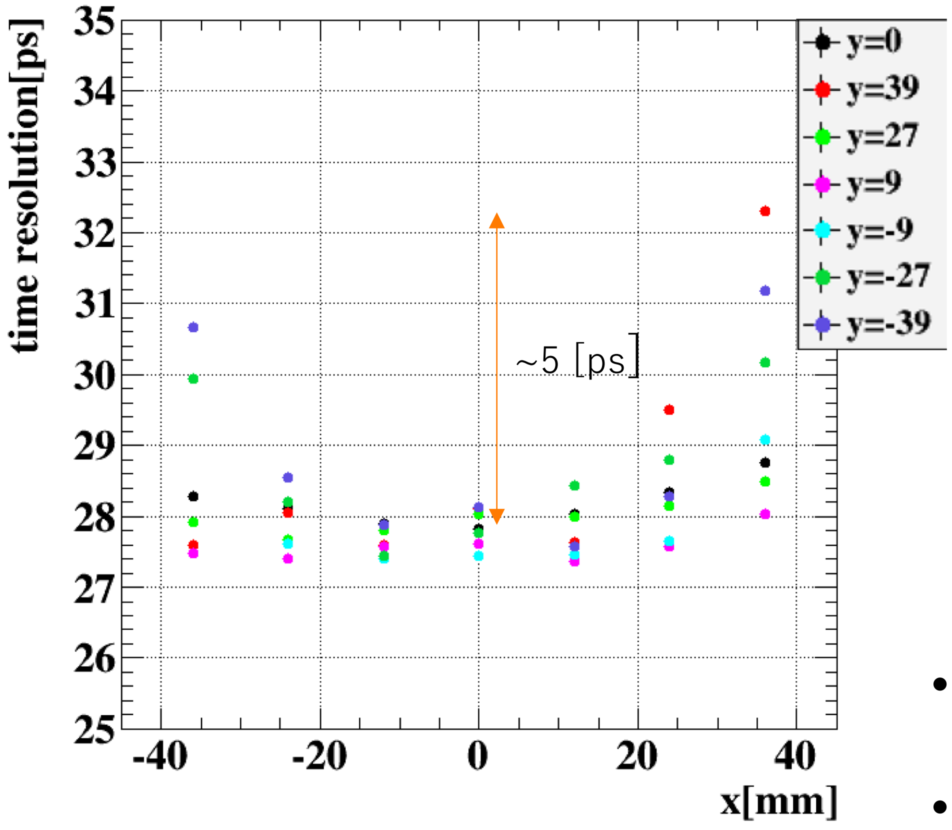


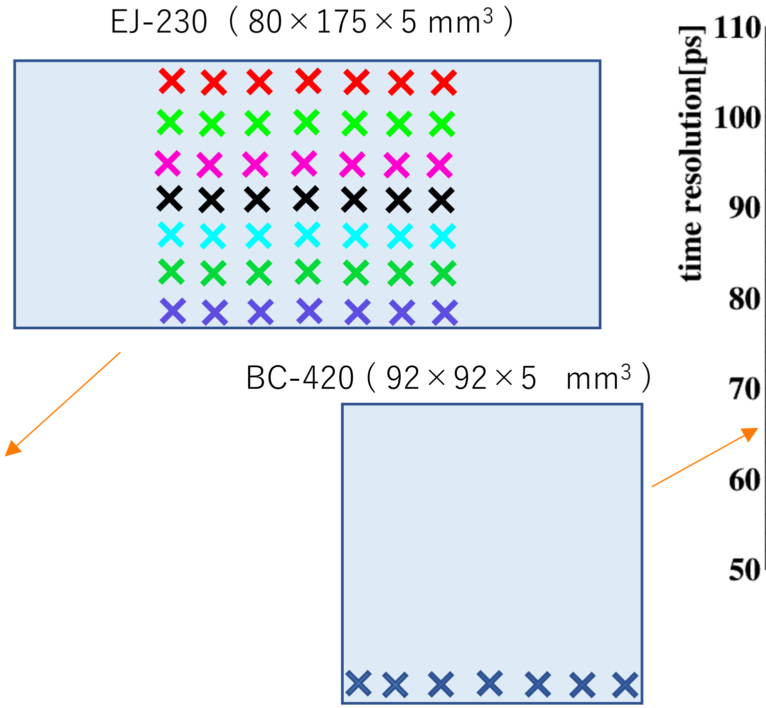
- New scintillator
  - EJ-230 (equivalent to BC-420)
  - Attenuation length 120 cm
  - 80×175×5 mm^3
- MPPCs
  - 4 series × 4 channels × 2 sides
  - Attached to PCBs
- Reflector : ESR (Polyester)

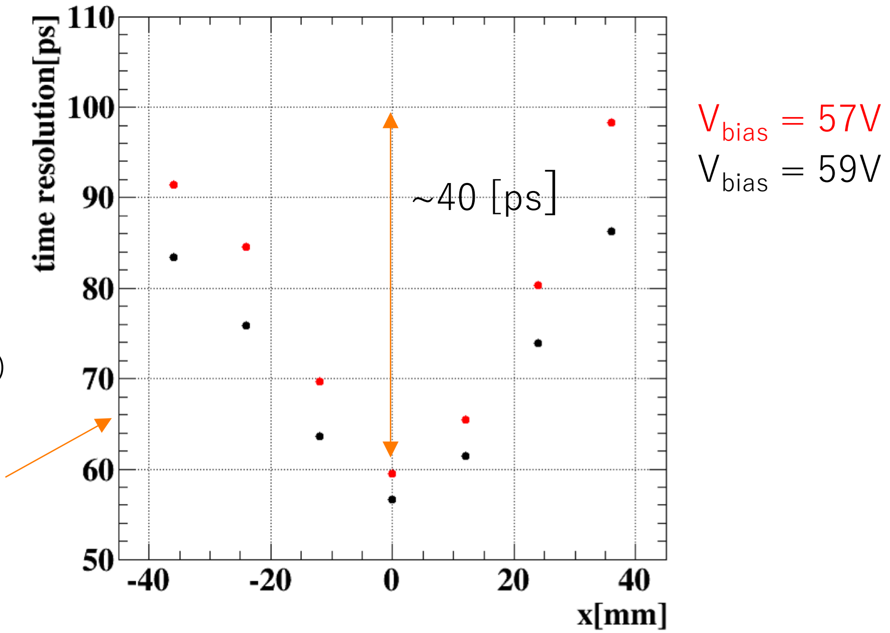
Scintillator	Risetime [ns]
BC-420 (92×92×5 mm^3)	2.017
EJ-230 (80×175×5 mm^3)	1.055

Faster risetime is supposed to make time resolution better

Time Resolution







- Time resolution got much better
  42 [ps] → 28 [ps] @ the center (Vover = 7 [V])
- Smaller position dependence of time resolution
  60 - 100 [ps] → 27 - 32 [ps]
  ←smaller position dependence of light yields

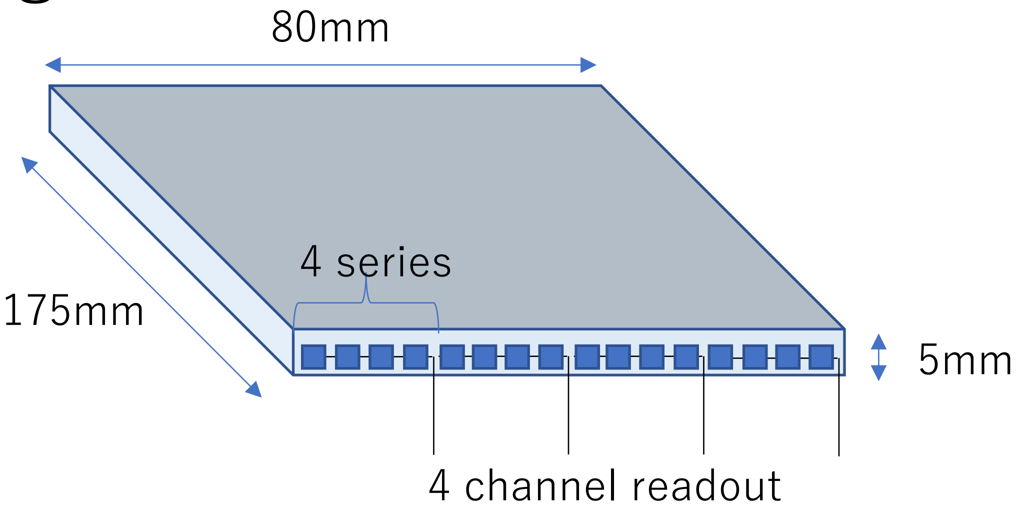
Decided to use a scintillator whose size is 80×175×5 [mm³]

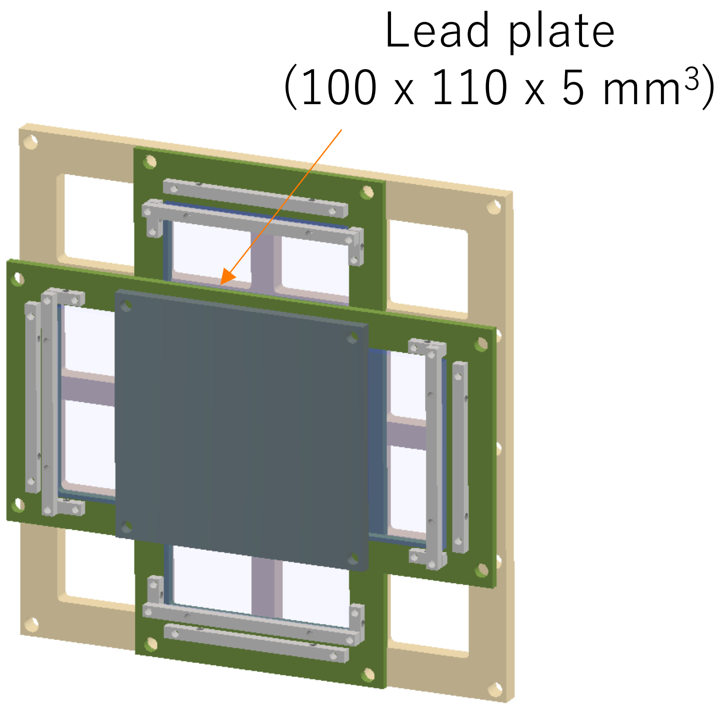
Summary

- The pre-shower counter for LXe detector timing calibration will be upgraded based on MEG II Timing Counter design
- Decided the counter design
  - 4 series connected MPPCs readout by 4 channels on each side
    - ➢ fast risetime and more MPPCs
    - ➢ Pulse height reduction caused by series connection
  - $80\times 175\times 5$ [mm^3] scintillator
    - ➢ time resolution is independent of scintillator size if coverage is equal
    - ➢ large size for large acceptance
    - ➢ a longer scintillator for smaller position dependence
- Achieved 28 [ps] time resolution at the center with small position dependence (< 5 [ps])

Prospect

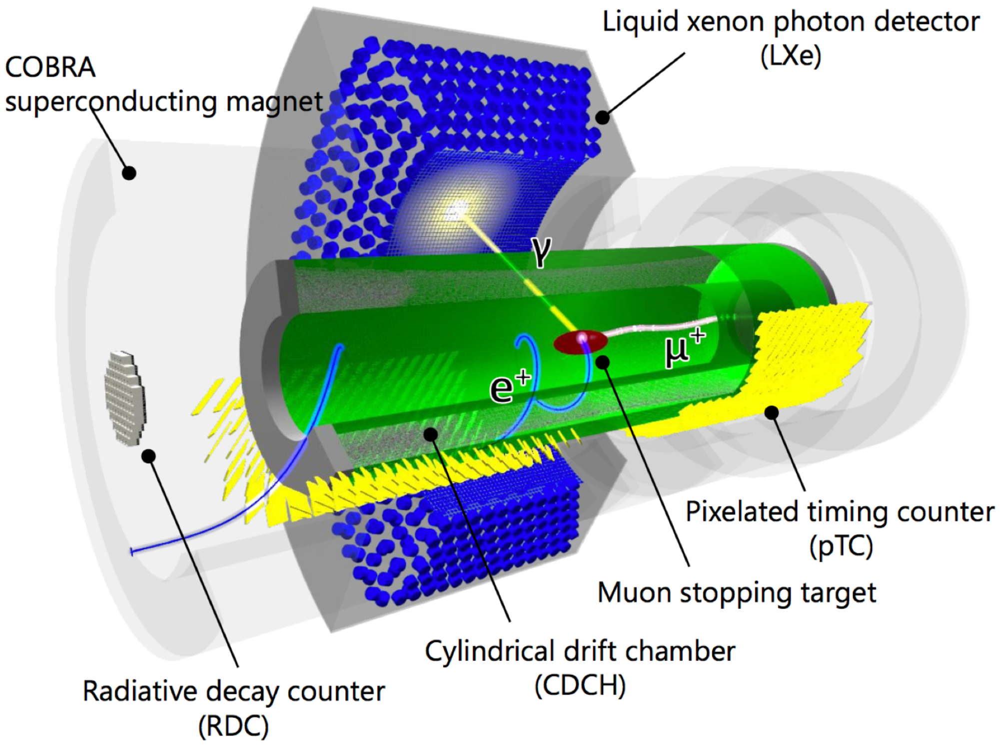
- Finish construction of pre-shower counter
- Measurements with the counter
  - with electronics used for operation
  - with γ source this summer
- Charge Exchange calibration run on Nov.





Back up

MEG II Experiment



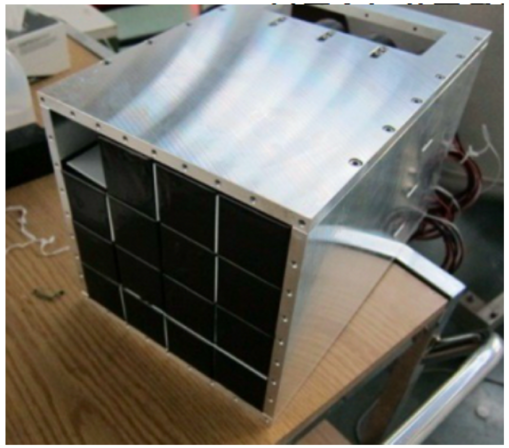
Upgraded from MEG

- μ^+ beam stopping rate
  3×10^7 /s → 7×10^7 /s
- Improved efficiency and resolution of each detector

Expected sensitivity

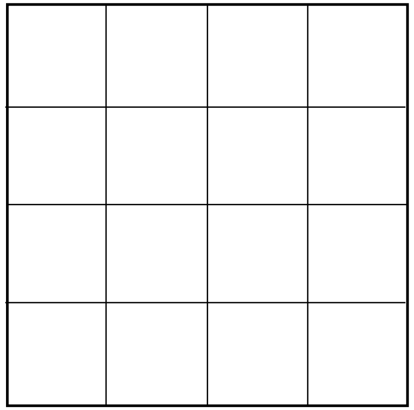
$4.2 \times 10^{-13} \rightarrow 4 \times 10^{-14}$

Calibration using Charge EXchange



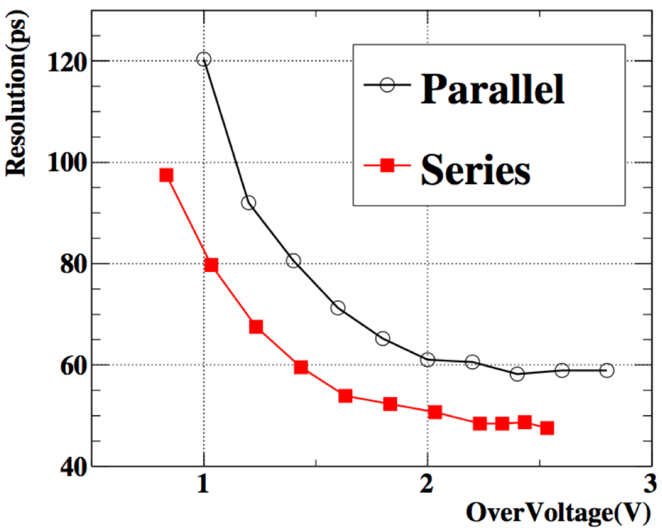
- Pre-shower counter for a timing measurement
- BGO crystal for energy and position measurements

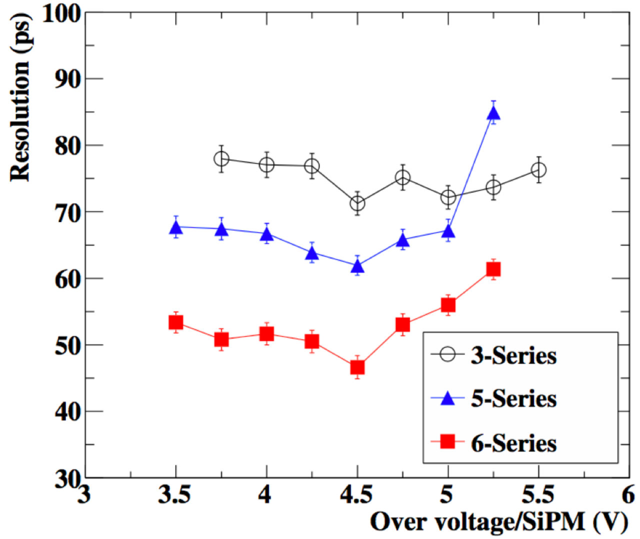
BGO crystal
- 4×4 arrayed
- Read out with fine mesh PMTs



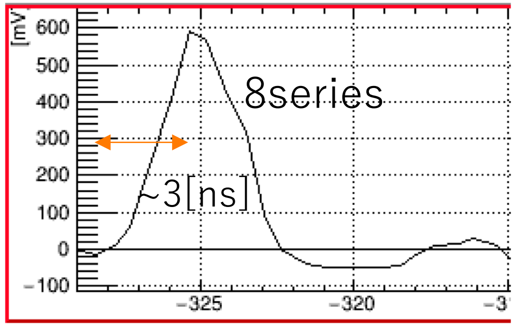
BGO crystals
$46 \times 46 \times 200$ mm^3 each

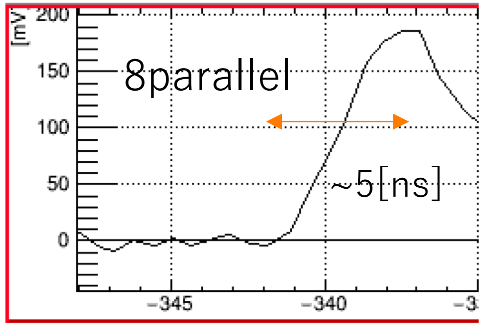
Previous Research about MEG II TC





M. Nishimura et al., Pixelated positron timing counter with SiPM- readout scintillator for MEG II experiment. In *Proceedings 4th Int. Conf. on New Photo-Detectors*, PoS(PhotoDet 2015)011, Mo- scow, Russia, (2016)





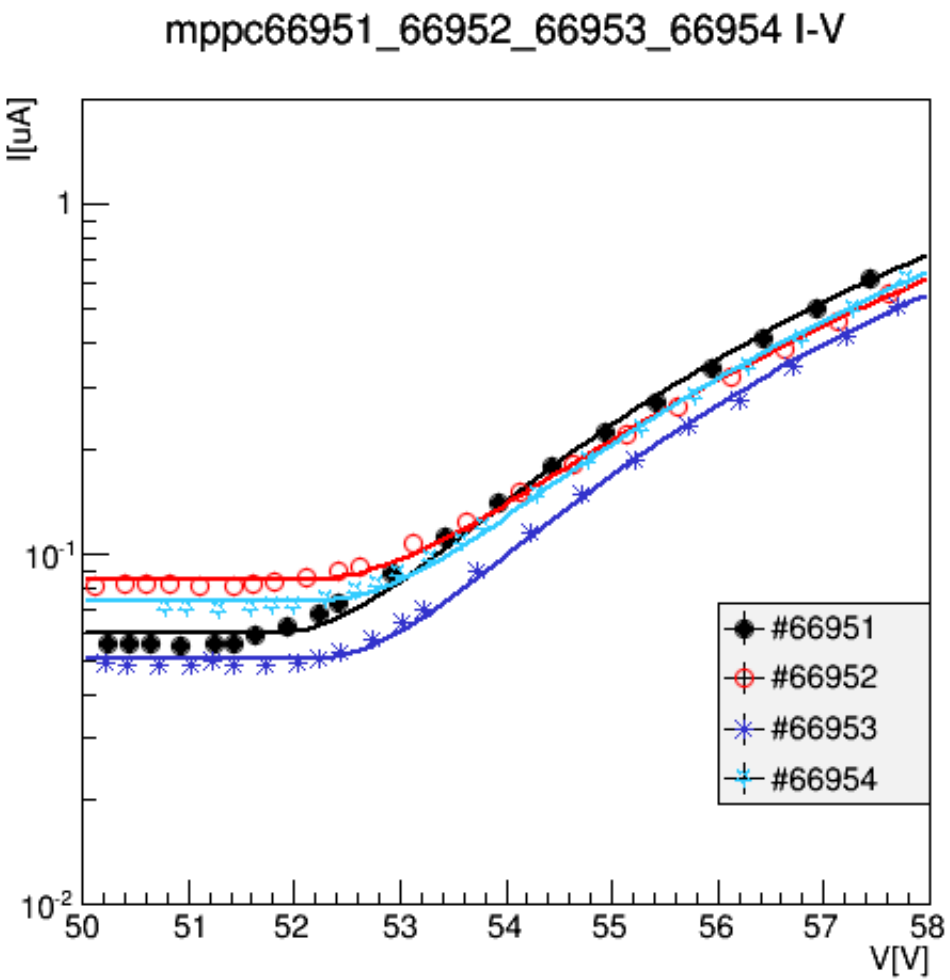
Reached 50 [ps] resolution

- $40 \times 90 \times 5$ [mm^3], BC422 scintillator
- 6 series SiPMs (ASD-NUV3S-P-50)

To achieve better resolution

- High light yield
  → more MPPCs
- Fast rise time
  → series > parallel
  because of smaller capacitance

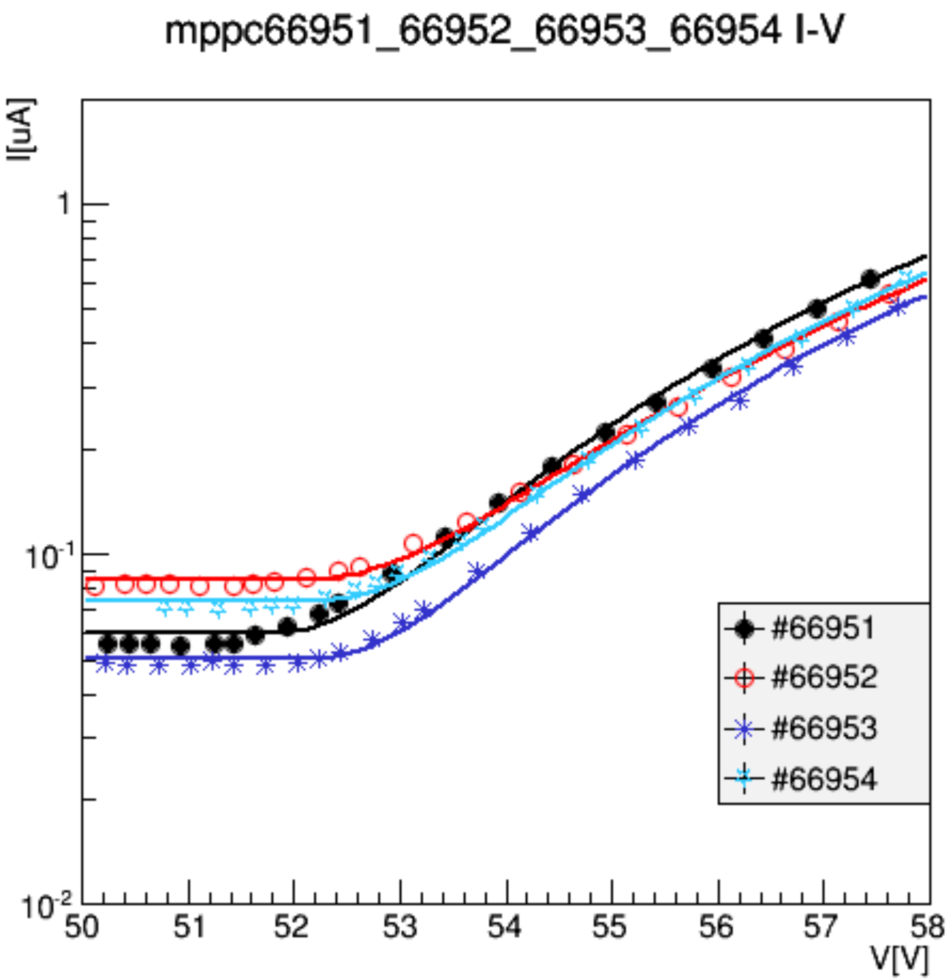
MPPC Selection



MPPCs connected in series or parallel must have similar characteristics.

- I-V measurement for 100 MPPCs
- Choose 36 MPPCs which have similar I-V curves

MPPC Selection

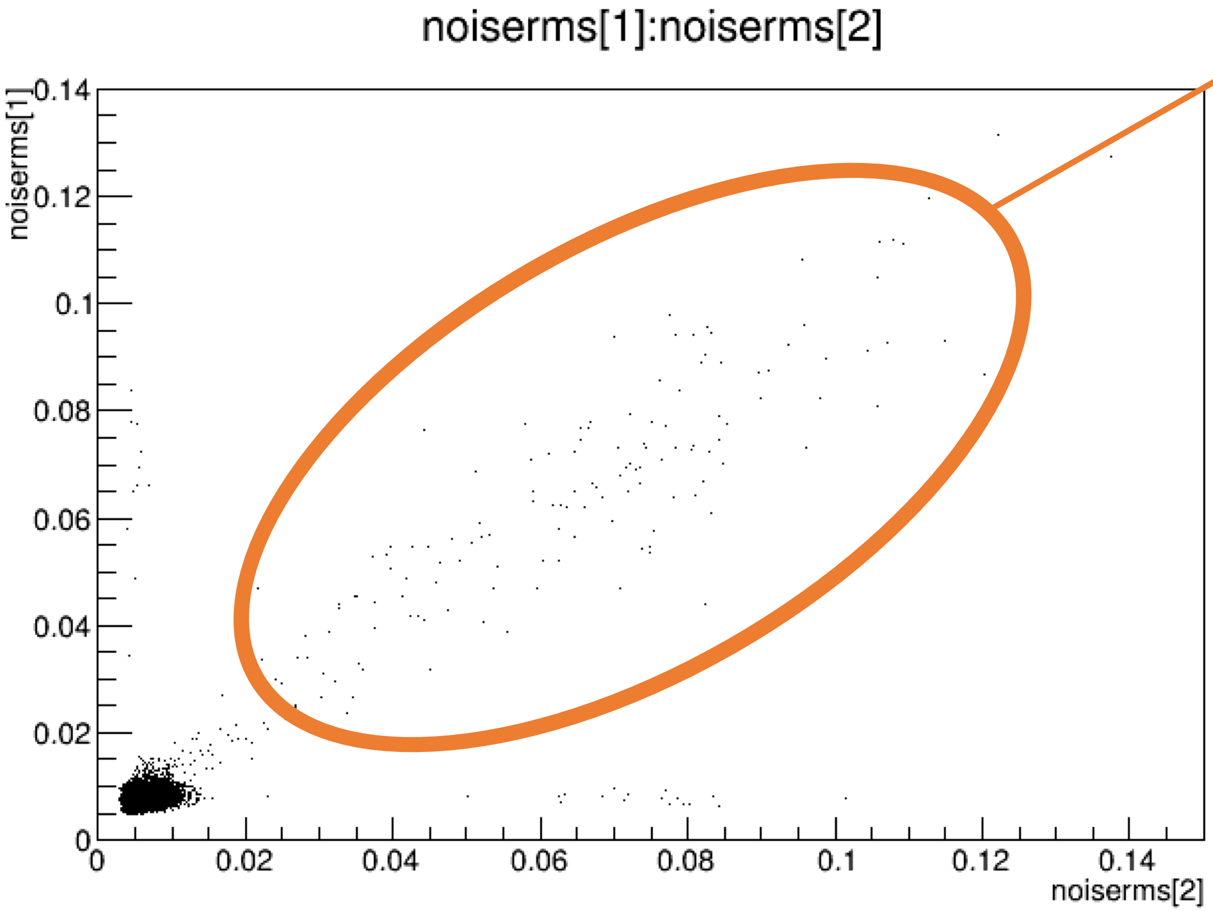


- I-V measurement for 100 MPPCs
- Fit the curve to the function

$$f(V) = \begin{cases} c & V < V_{br} \\ a * (V - V_{br})^2 + c & V > V_{br} \end{cases}$$

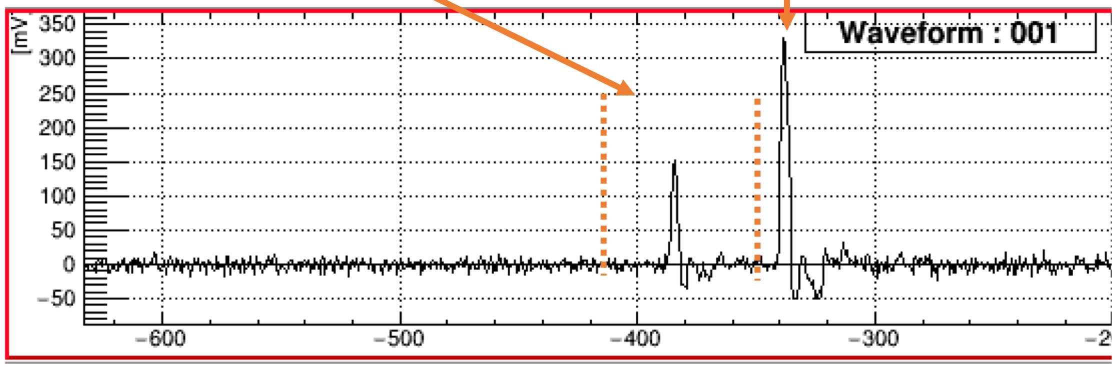
- Made clusters considering V_{op} , I_{op} , a

Event Selection



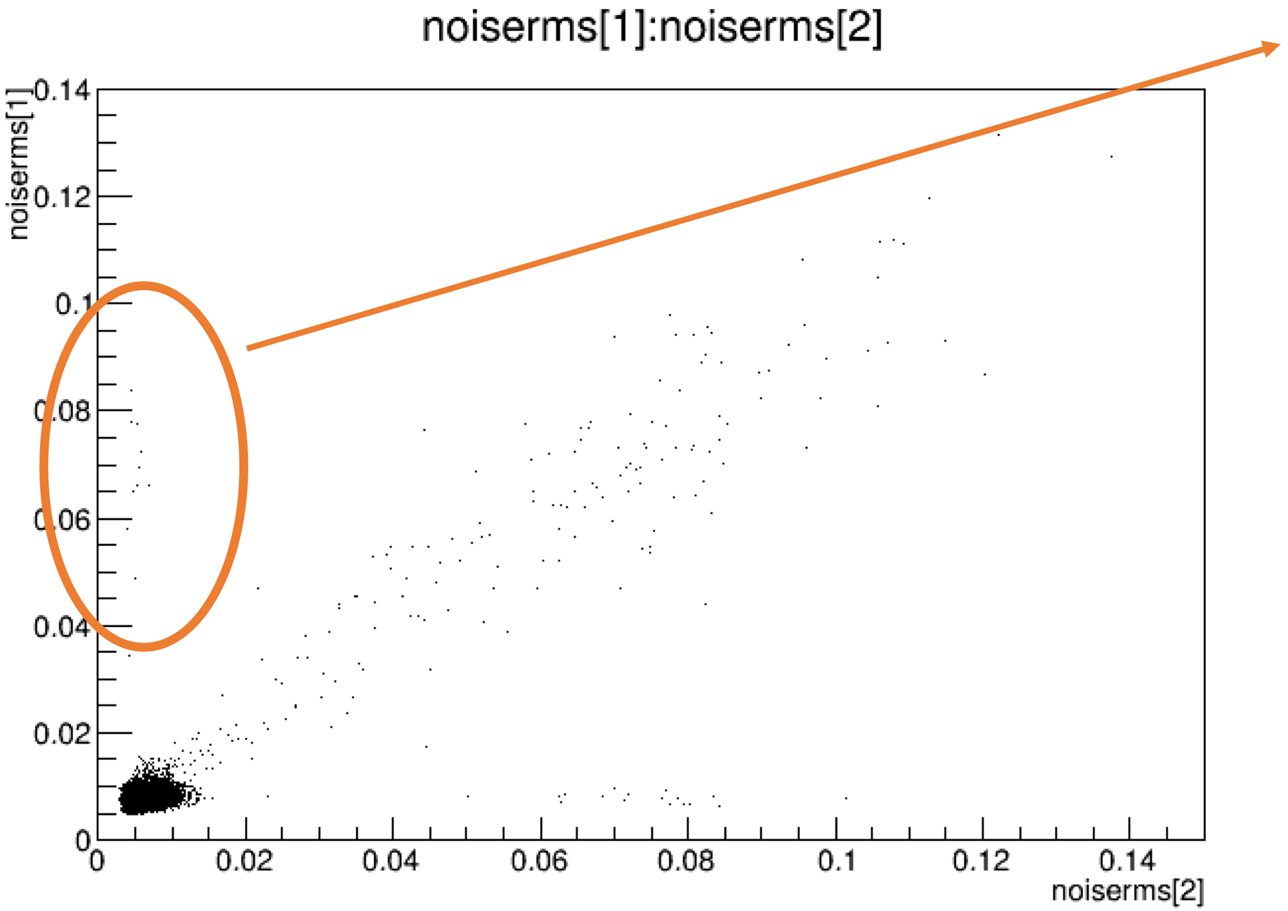
calculation area for baseline RMS

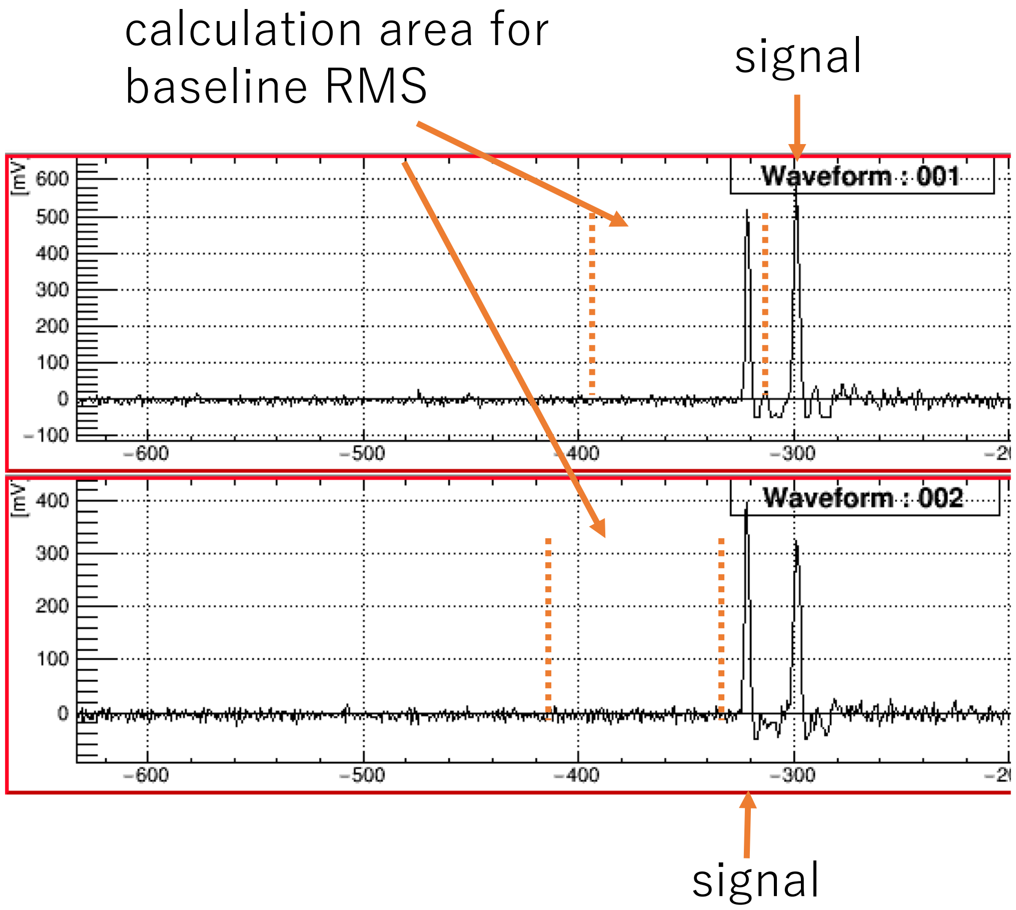
signal



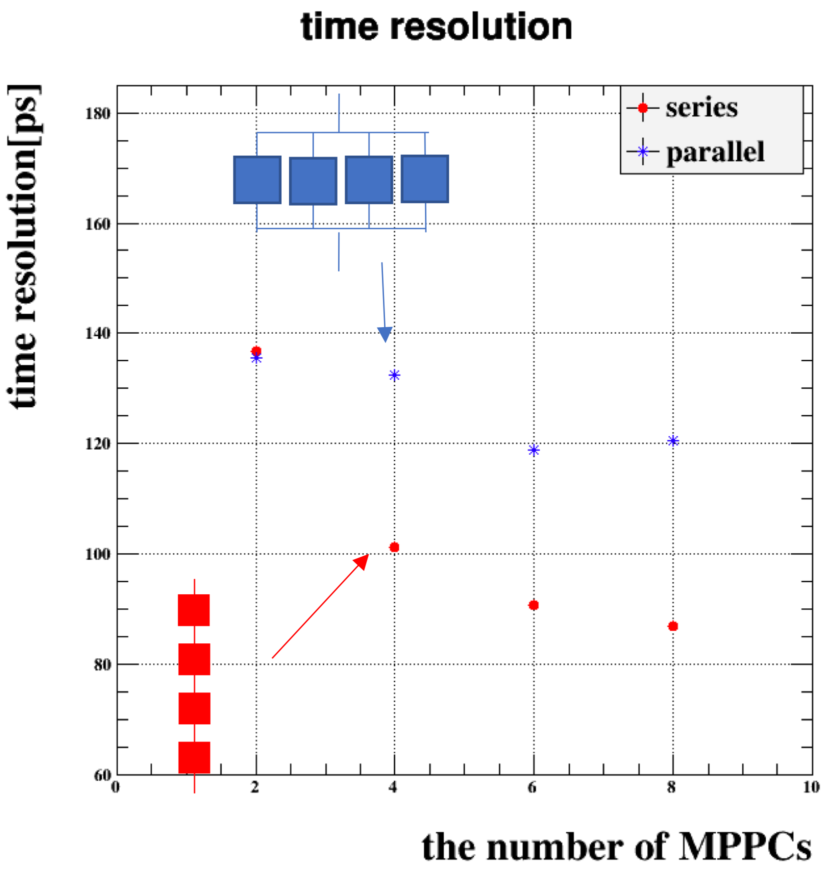
A signal is found by searching a peak.
Some events include a signal in noise calculation area.
Therefore, these events should be cut.

Event Selection



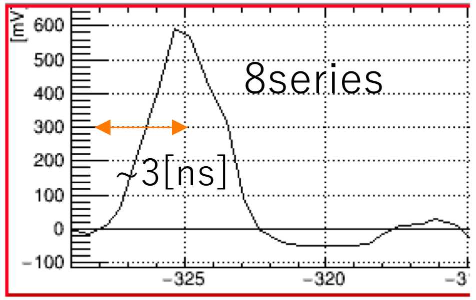


Comparison of Series/Parallel Connection

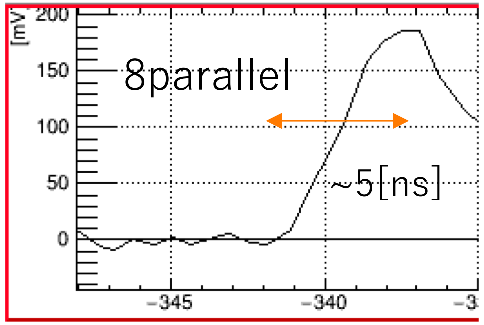


Checked difference between series and parallel connection. Resolution of series connection is superior to that of parallel as expected.

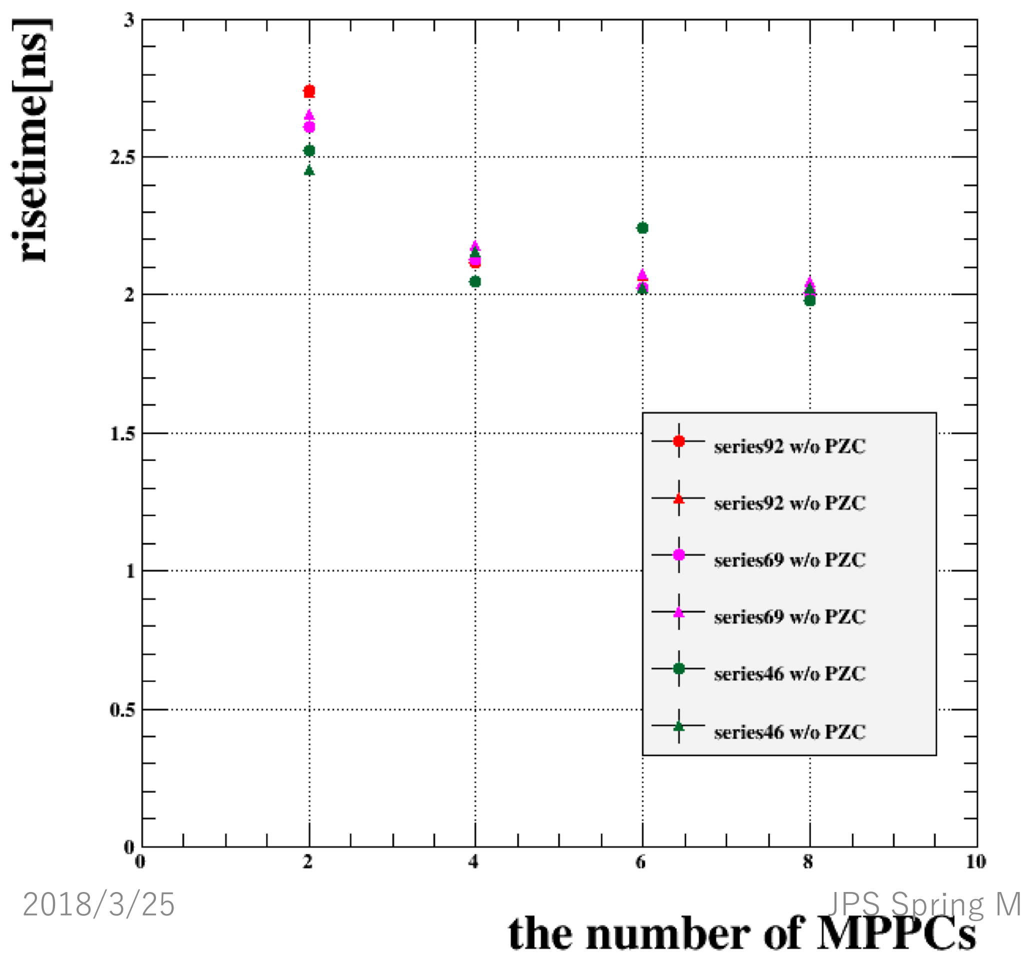
Series
- Resolution improves as more MPPCs are connected



Parallel
- Resolution doesn't improve with many MPPCs due to large capacitance

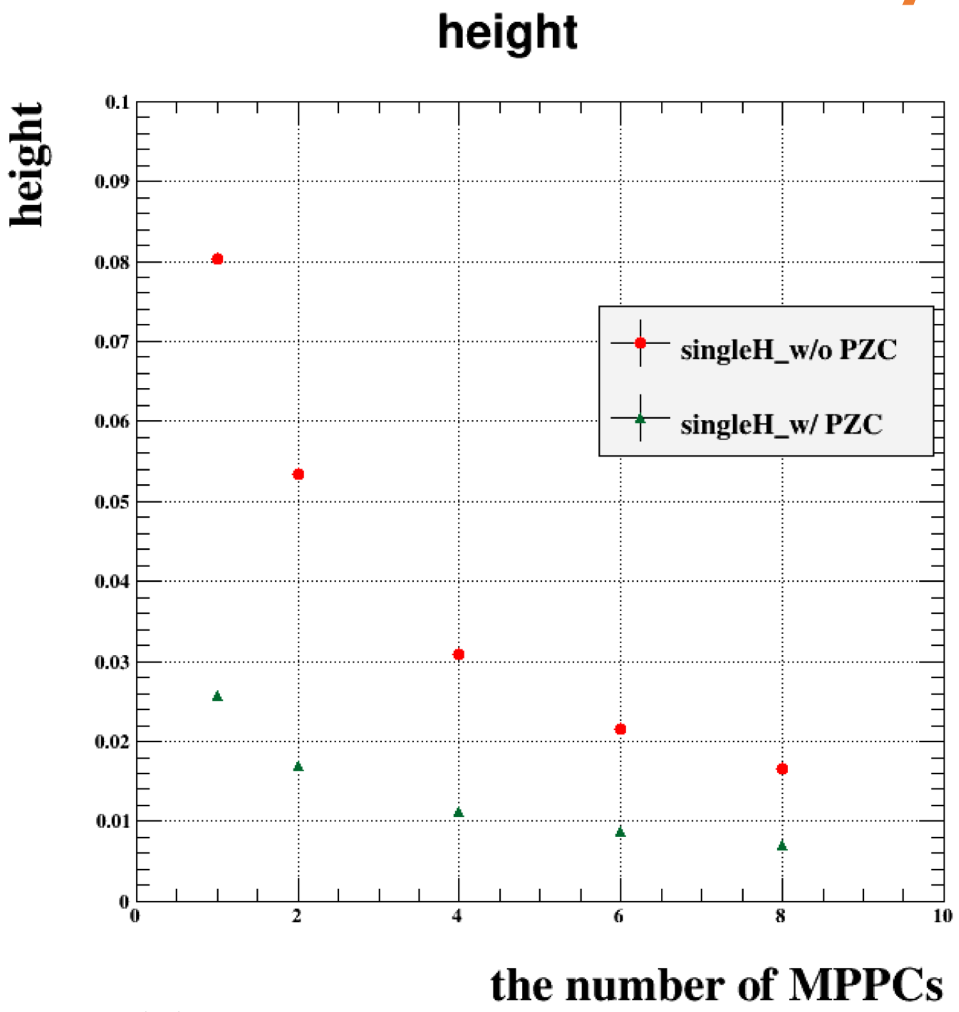


Risetime w/o PZC



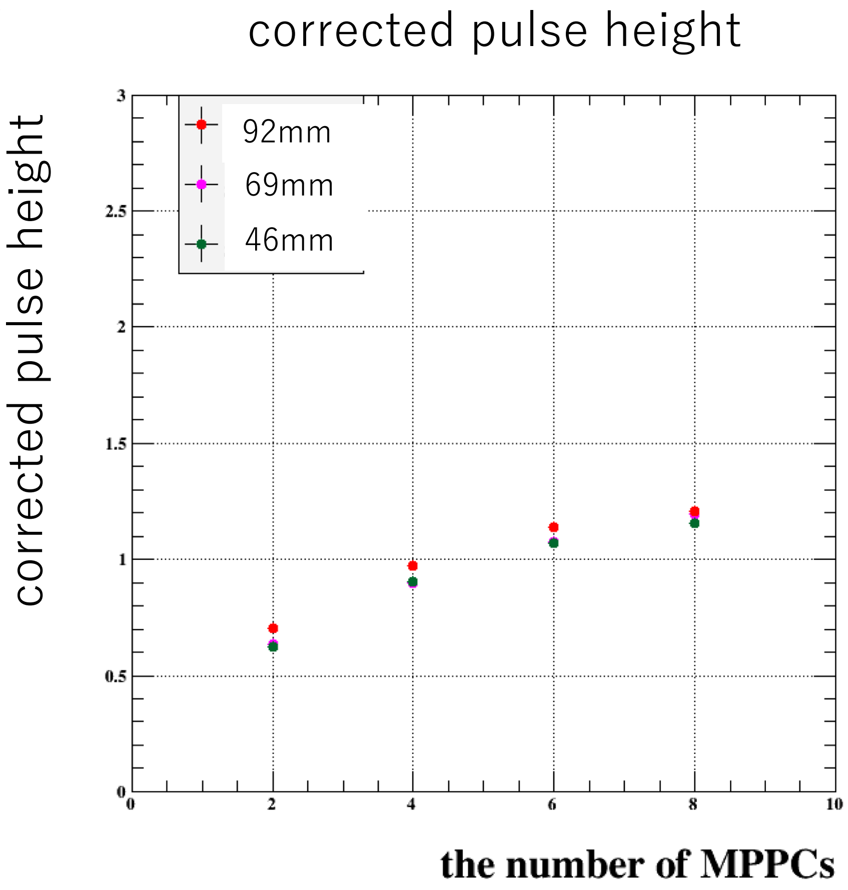
- Independent of a scintillator size
- Decrease from 2 MPPCs to 4 MPPCs, but become almost stable after that
  → time response of the scintillator?

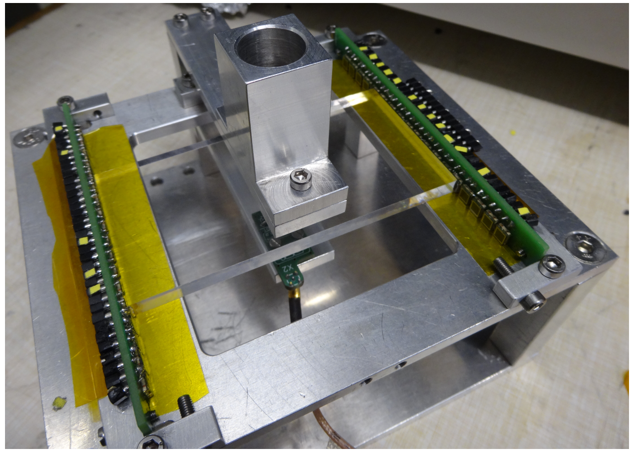
Height Difference of Single Photon Caused by Series Connection



- Height is apparently reduced by series connection
- Decrease tendencies are not the same between w/and w/o PZC

Measured Result for Light Yield

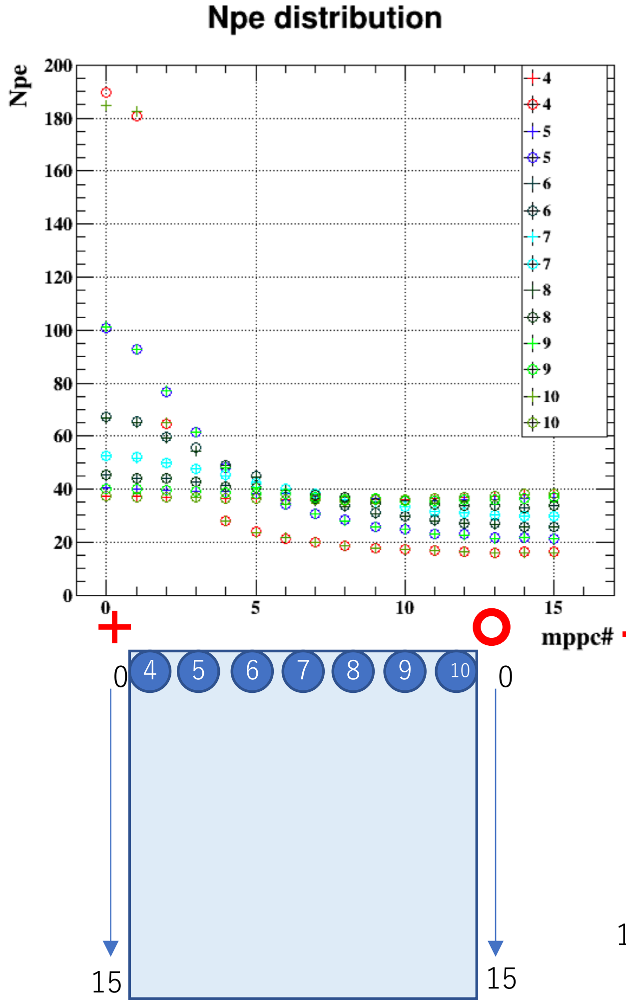




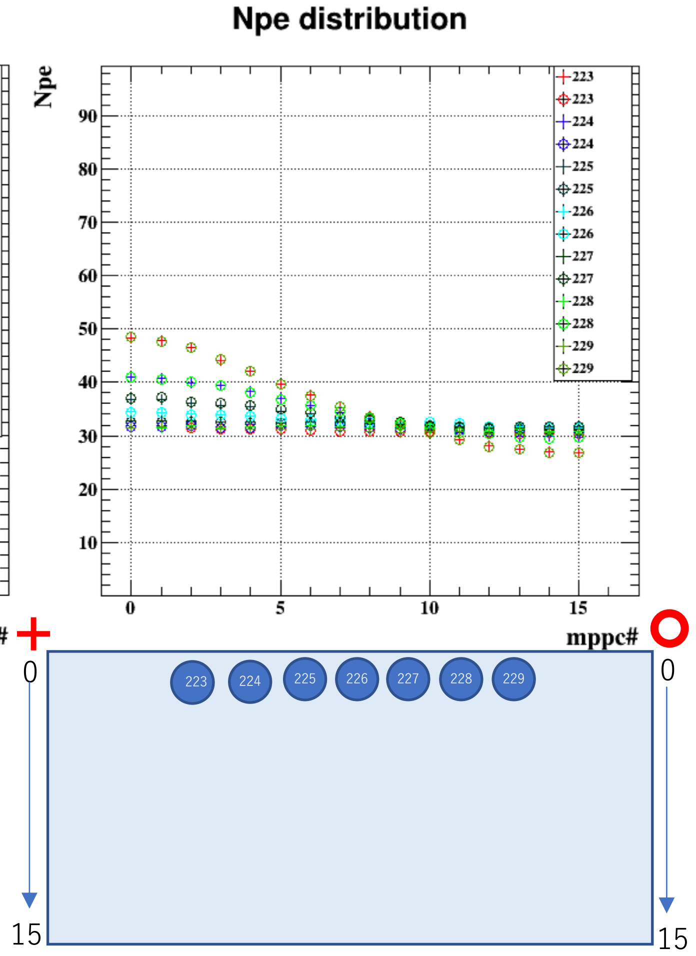
- Heights corrected by coverage are almost the same among the three
  → Consistent with the simulation

Light Yield Simulation

$92 \times 92 \times 5$ [mm^3]

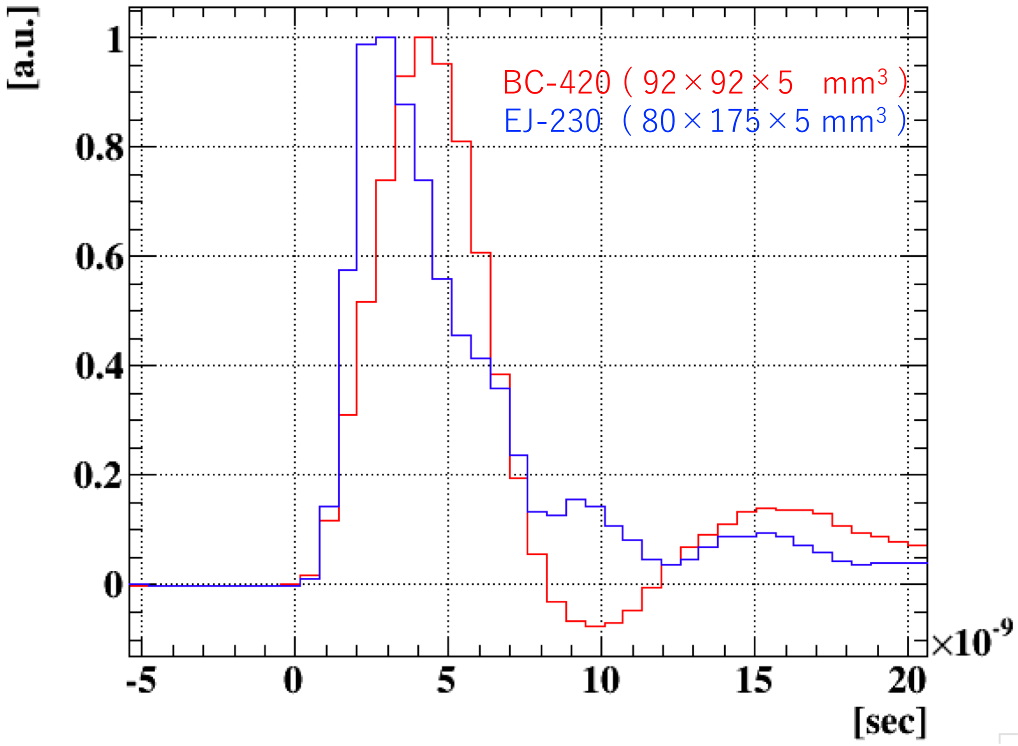


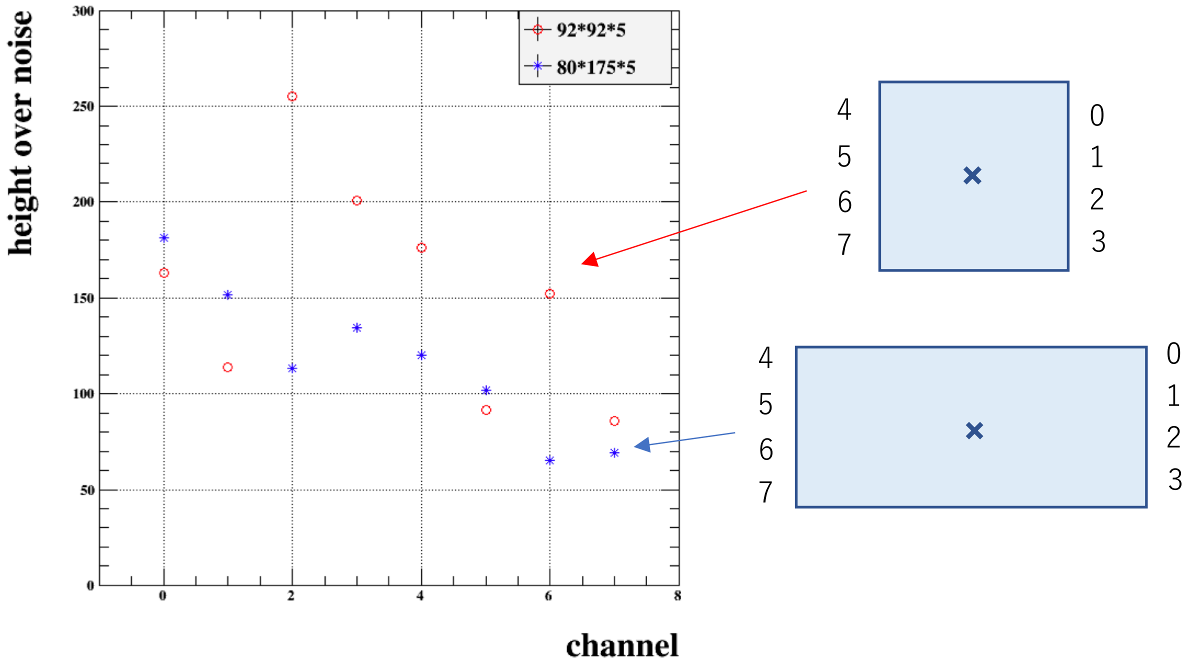
$80 \times 175 \times 5$ [mm^3]



- If the RI is on the nearest position to one side (4, 10), the highest light yields is about 9 times higher than the lowest one.
- The difference gets smaller as the RI gets far from the side MPPCs attach to.
- If the length of scintillator is longer, the light yield difference is less.
  → Decided to use a scintillator whose size is $80 \times 175 \times 5$ [mm^3]

Time Resolution Improvement





Scintillator	Risetime [ns]
BC-420 ($92 \times 92 \times 5$ mm^3)	2.017
EJ-230 ($80 \times 175 \times 5$ mm^3)	1.055

- Risetime is much faster
- S/N became lower overall.
  ← Height became relatively low.
  ← Equivalent noise level.

Spec Sheets

Eljen Technology

PROPERTIES	EJ-228	EJ-230
Light Output (% Anthracene)	67	64
Scintillation Efficiency (photons/1 MeV e^-)	10,200	9,700
Wavelength of Maximum Emission (nm)	391	391
Light Attenuation Length (cm)	-	120
Rise Time (ns)	0.5	0.5
Decay Time (ns)	1.4	1.5
Pulse Width, FWHM (ns)	1.2	1.3
H Atoms per cm³ ($\times 10^{22}$)	5.15	5.15
C Atoms per cm³ ($\times 10^{22}$)	4.69	4.69
Electrons per cm³ ($\times 10^{23}$)	3.33	3.33
Density (g/cm³)	1.023	1.023

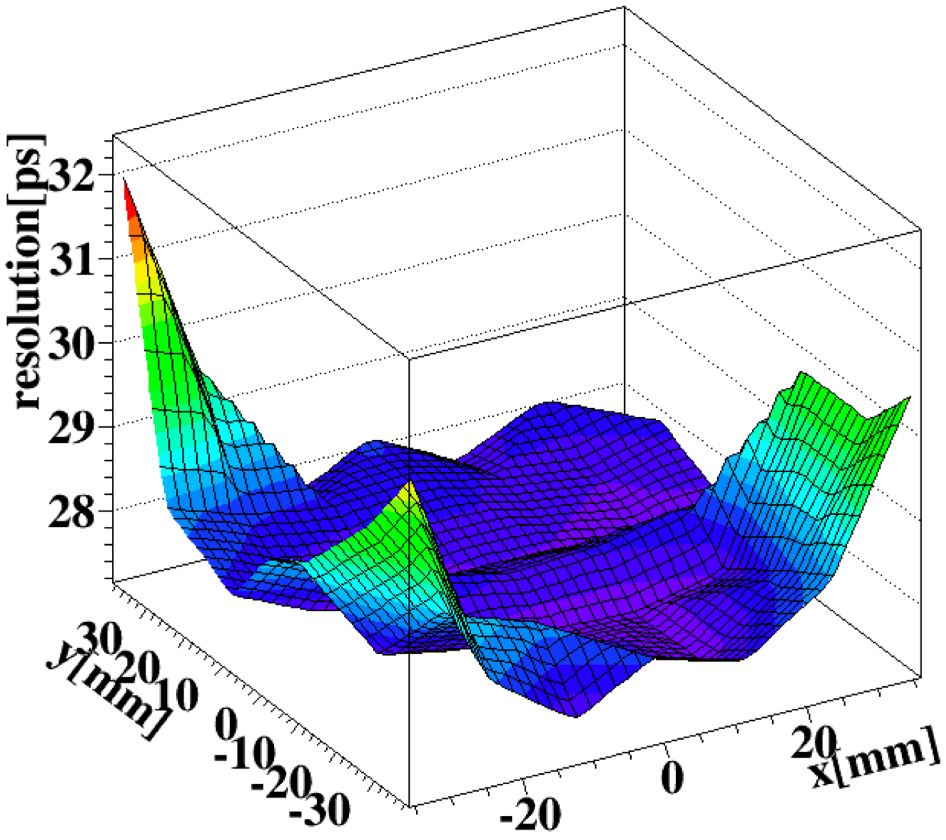
Saint Gobain

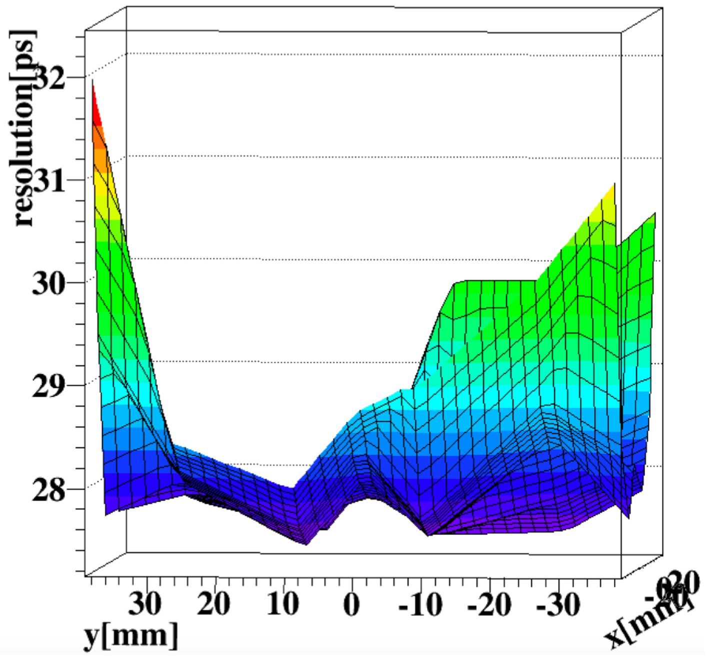
	BC-418	BC-420	BC-422
Scintillation Properties			
Light Output, %Anthracene	67	64	55
Rise Time, ns	0.5	0.5	0.35
Decay Time (ns)	1.4	1.5	1.6
Pulse Width, FWHM, ns	1.2	1.3	1.3
Wavelength of Max. Emission, nm	391	391	370
Light Attenuation Length, cm*	NA**	140	NA**
Bulk Light Attenuation Length, cm	100	110	8
Atomic Composition			
No. H Atoms per cc ($x10^{22}$)	5.21	5.21	5.19
No. C Atoms per cc ($x10^{22}$)	4.74	4.74	4.71
Ratio H:C Atoms	1.100	1.100	1.102
No. of Electrons per cc ($x10^{23}$)	3.37	3.37	3.34

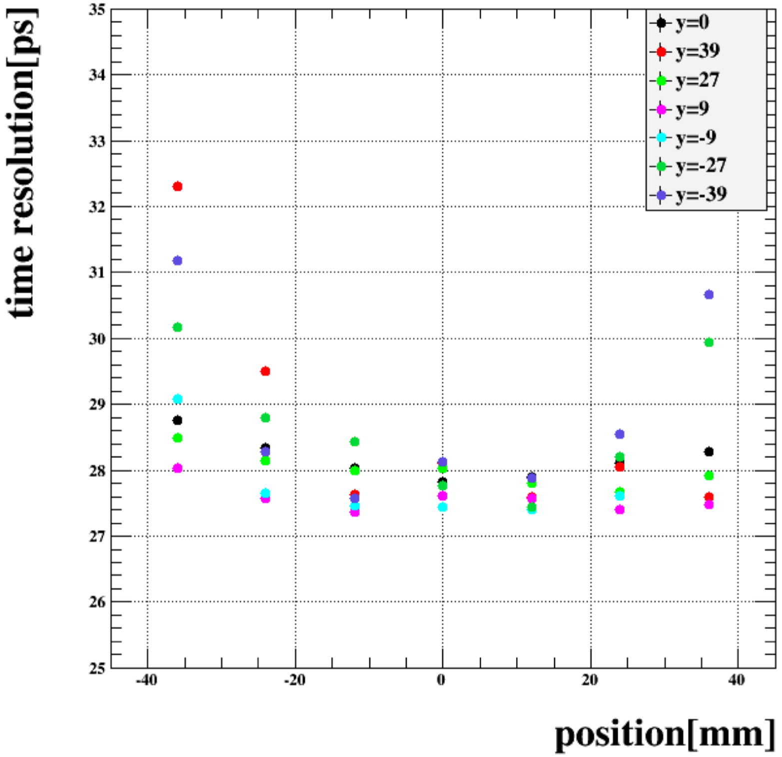
*The typical 1/e attenuation length of a 1x20x200cm cast sheet with edges polished as measured with a bialkali photomultiplier tube coupled to one end.

** Scintillator recommended for use in small sizes; therefore, the 1/e attenuation length values are not applicable.

Time Resolution

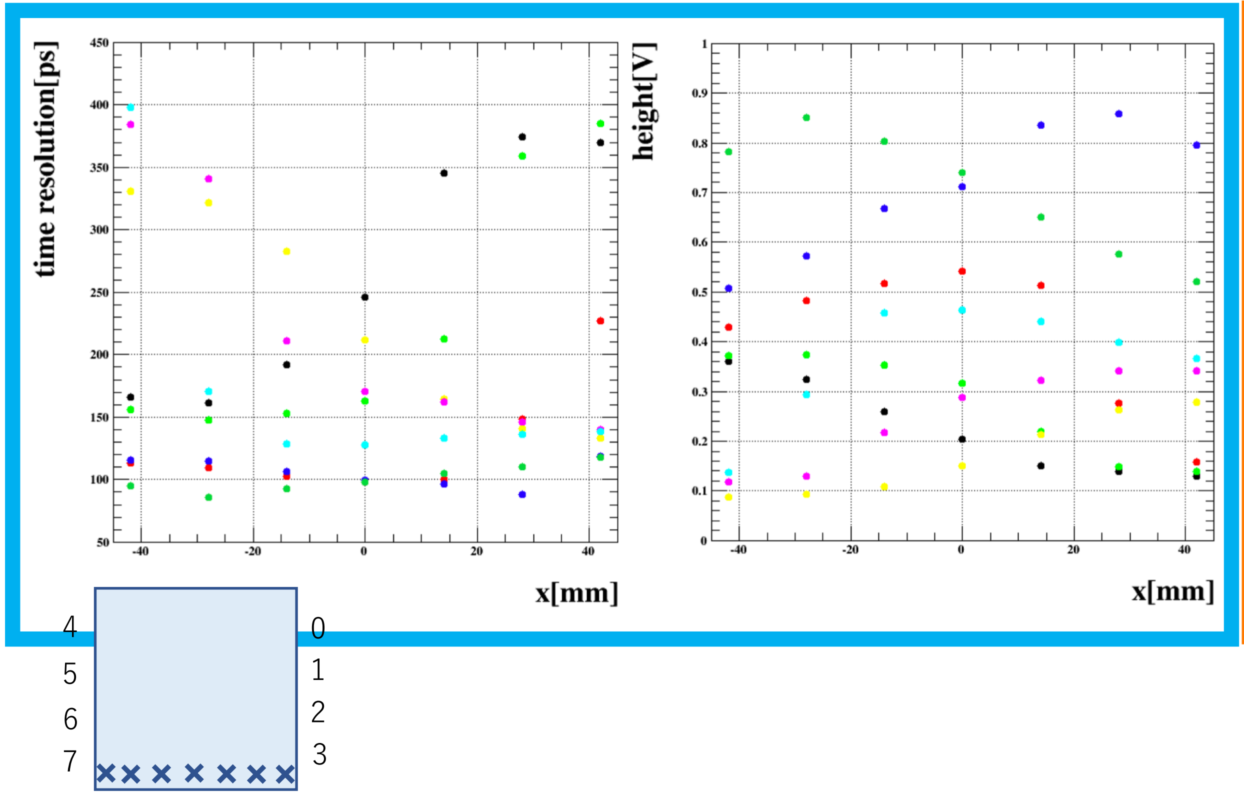


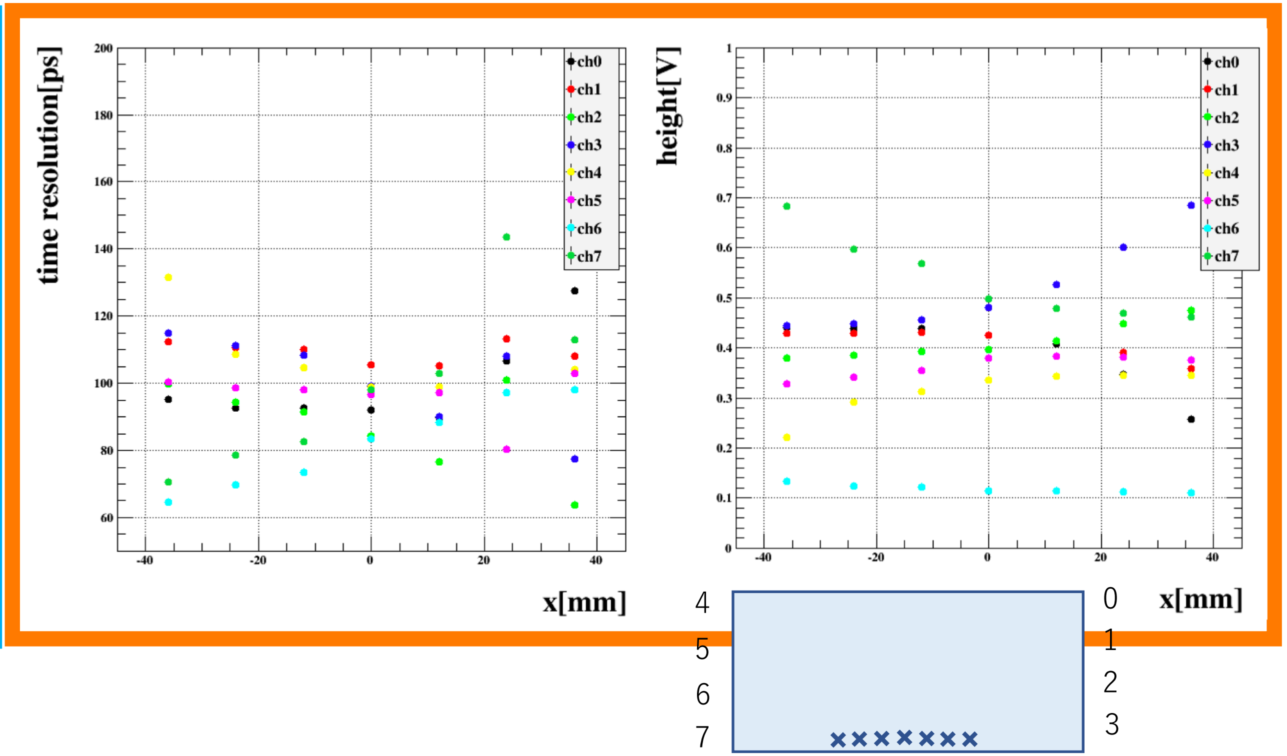




- Better resolution near the center
  ← Height
- 27 ~ 32 [ps]

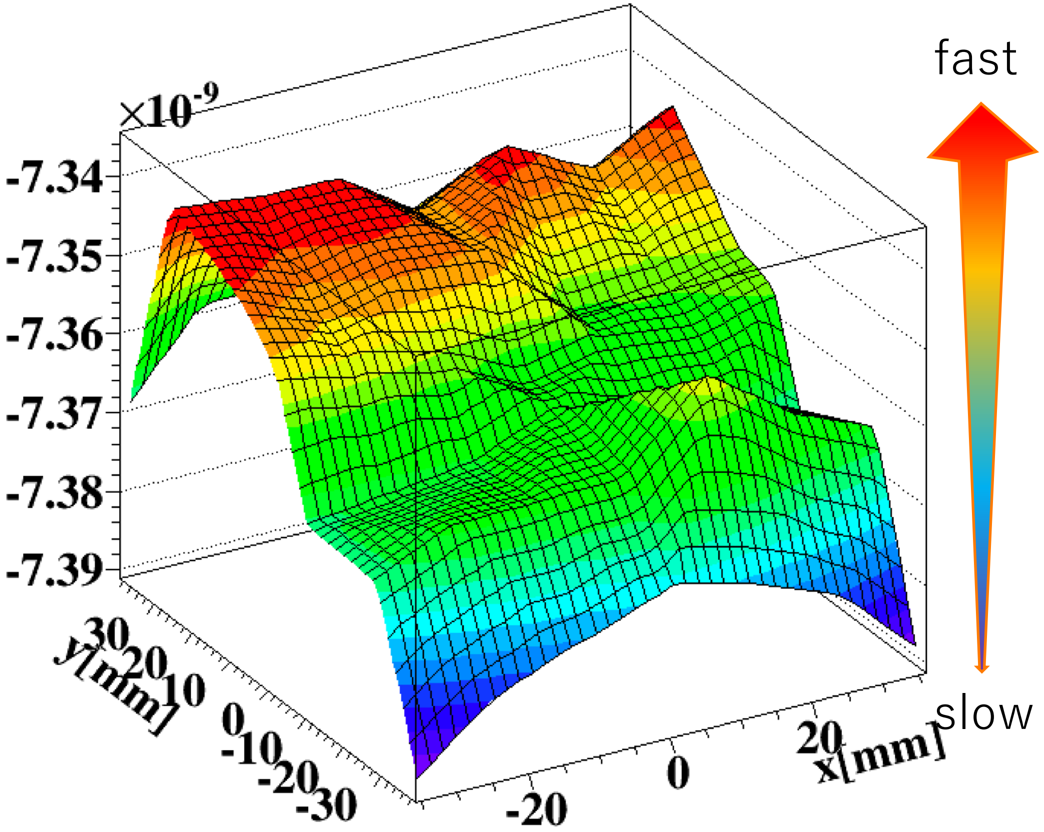
Position Dependence of Each Channel

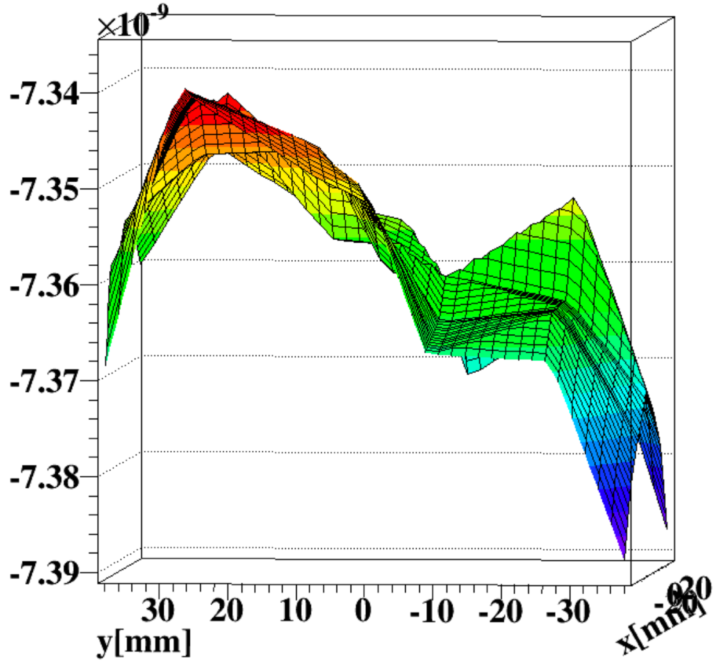


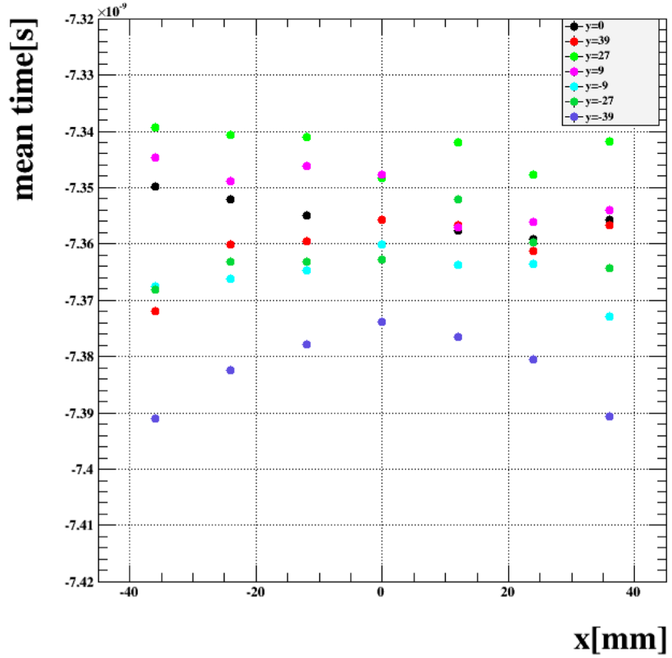


- Time resolution of each channel got better overall and its position dependence became less comparing to the smaller scintillator
- Position dependence of height also smaller

Mean Time



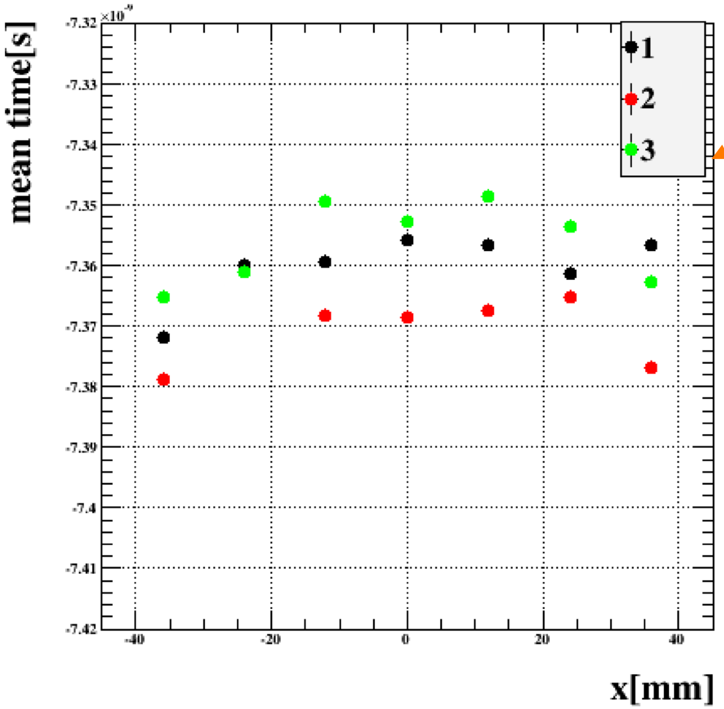


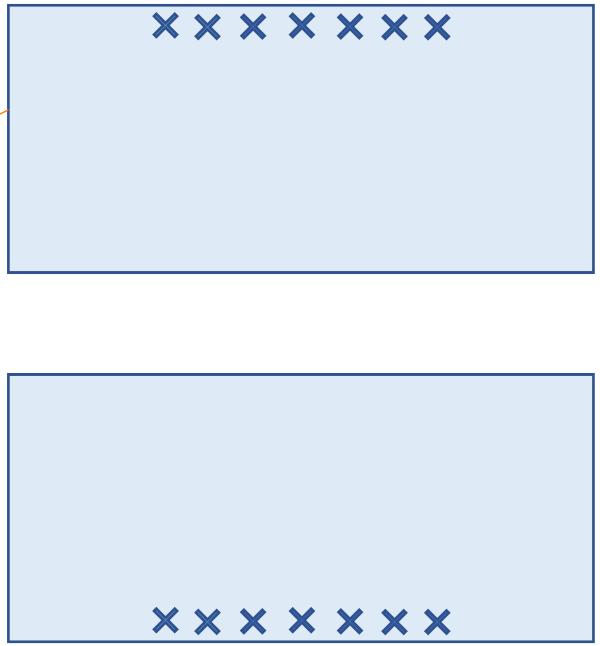


- Faster near the center
- X dependence is smaller near the center
- Y asymmetry
  → scintillator, MPPCs?

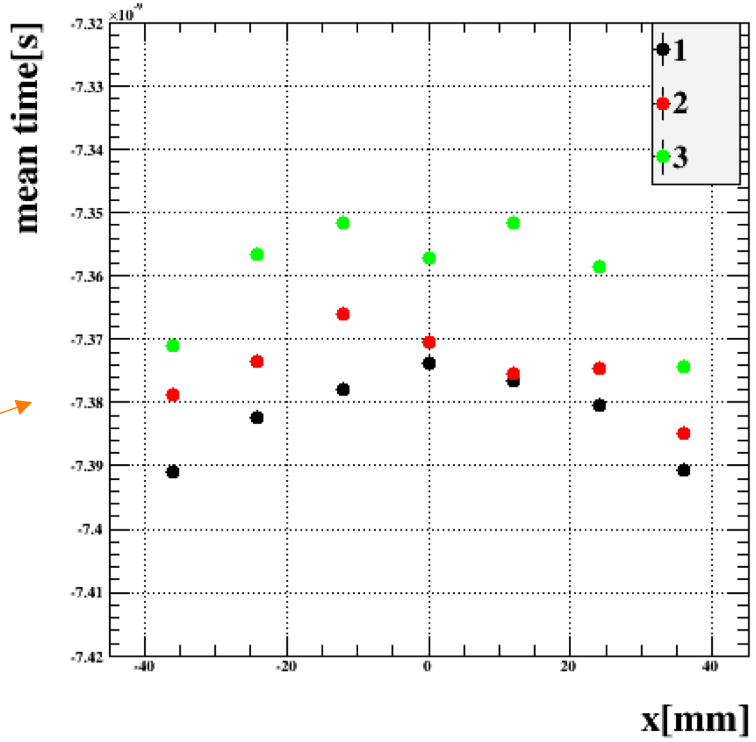
Mean Time Reproducibility Check

y = 39 mm





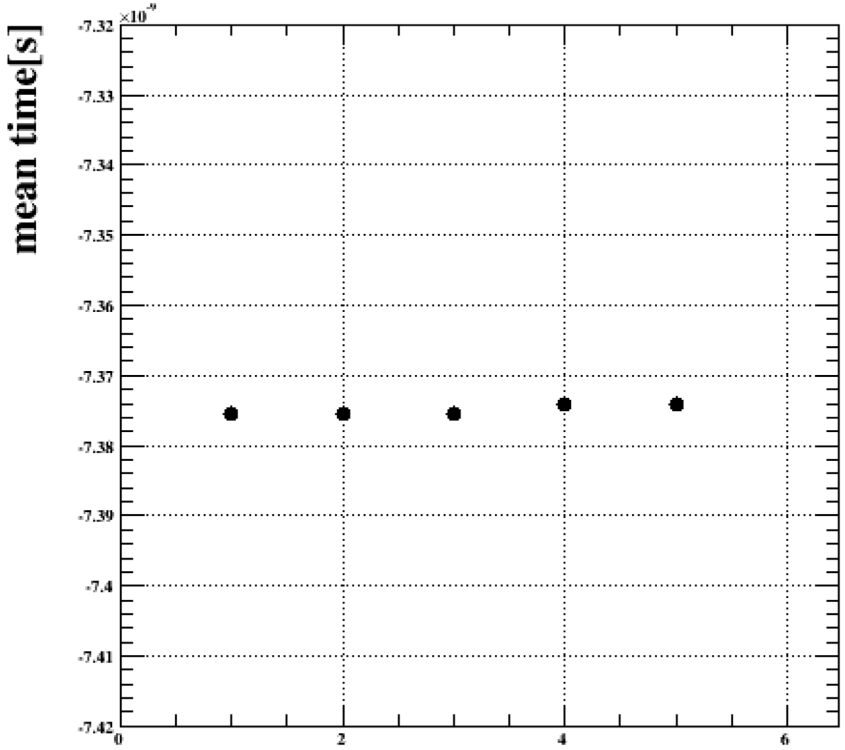
y = -39 mm



- Measured again rotating the scintillator by 180 degree
- Mean time changes in ~20[ps]
  - Not dependent on scintillator position and MPPCs
  - No reproducibility

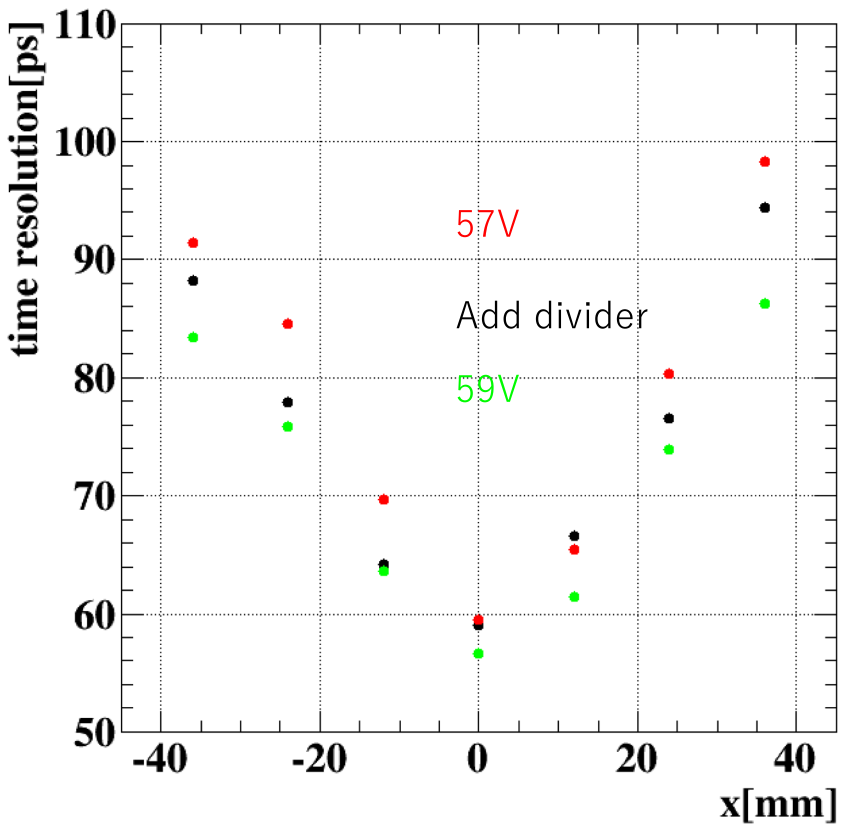
→ Reattachment of MPPCs and a scintillator?

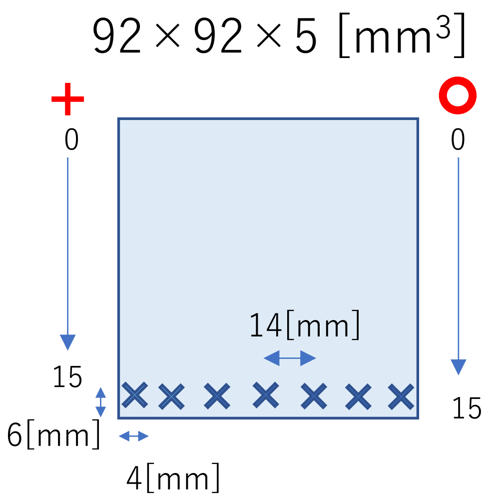
Mean Time Reproducibility Check

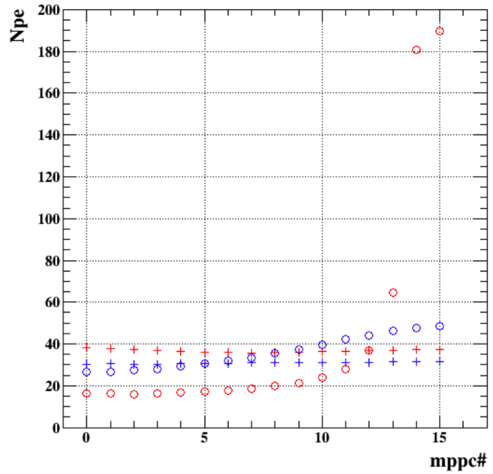


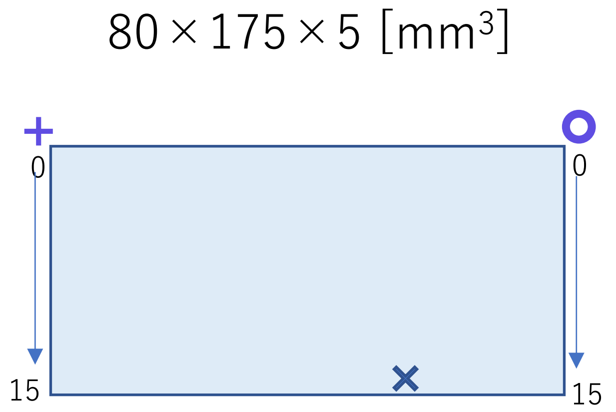
- Repeated the measurement w/ nothing in in-between
- Mean time is stable during 5 measurements
  → Reattachment of MPPCs and a scintillator may affects mean time
  → Should be measured after attaching them w/ optical cement

Light Yield Position Dependence





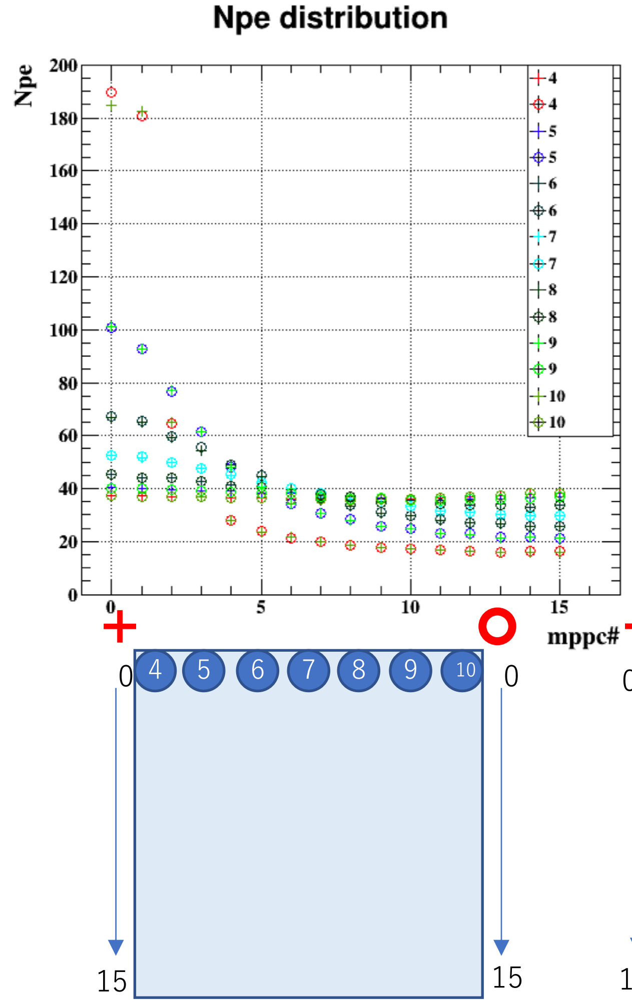




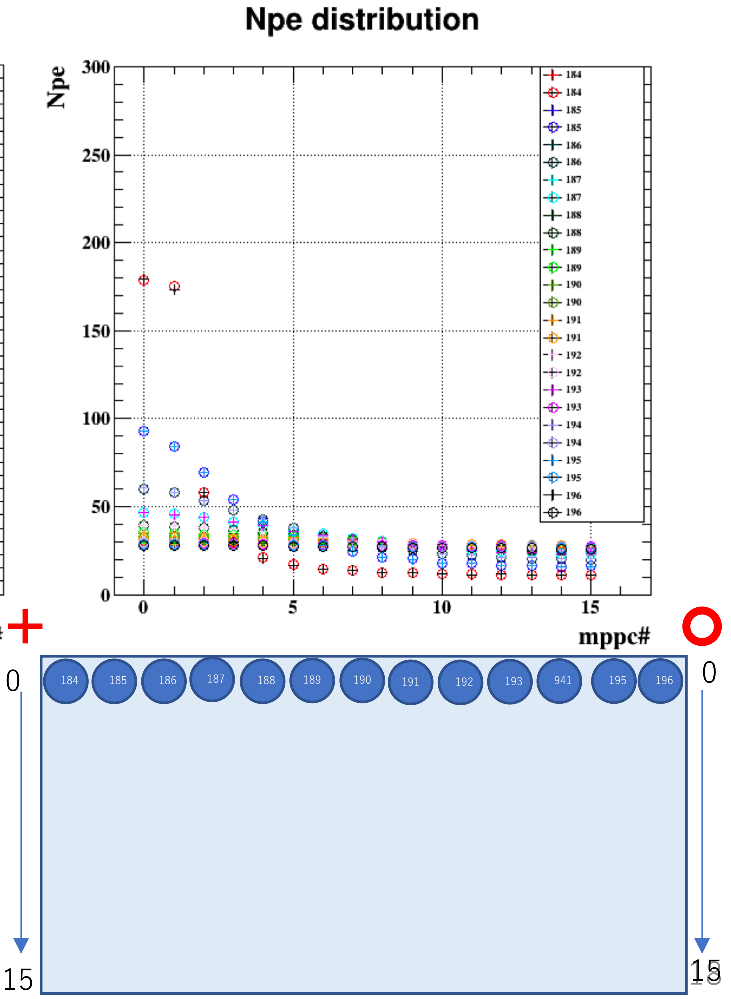
- When RI is far from the center, light yields of some channels are too small depending on their positions
  →less statistics & worse S/N
  →large position dependence of time resolution
- The light yield difference got smaller as the RI gets far from the side MPPCs attach to.
- According to simulations, if the length of scintillator is longer, the light yield difference is less when RI is put on the same distance from the center.

Light Yield Simulation

$92 \times 92 \times 5$ [mm^3]



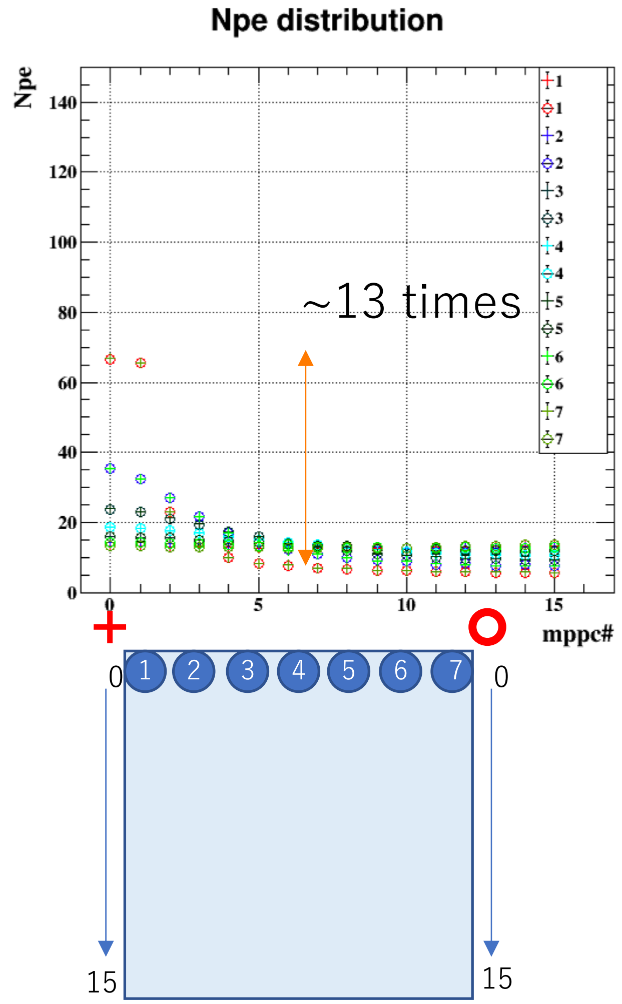
$92 \times 176 \times 5$ [mm^3]



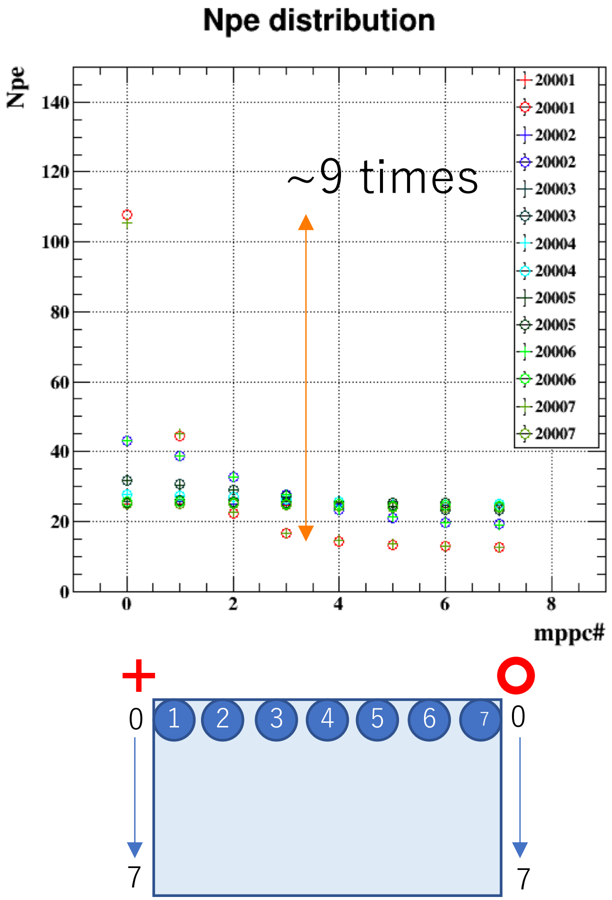
- Even if the length of scintillator is longer, the light yield difference is large if the RI is near to one side.
  →Small position dependence can be limited to an area near the center.

Light Yield Simulation

$92 \times 92 \times 5$ [mm^3]

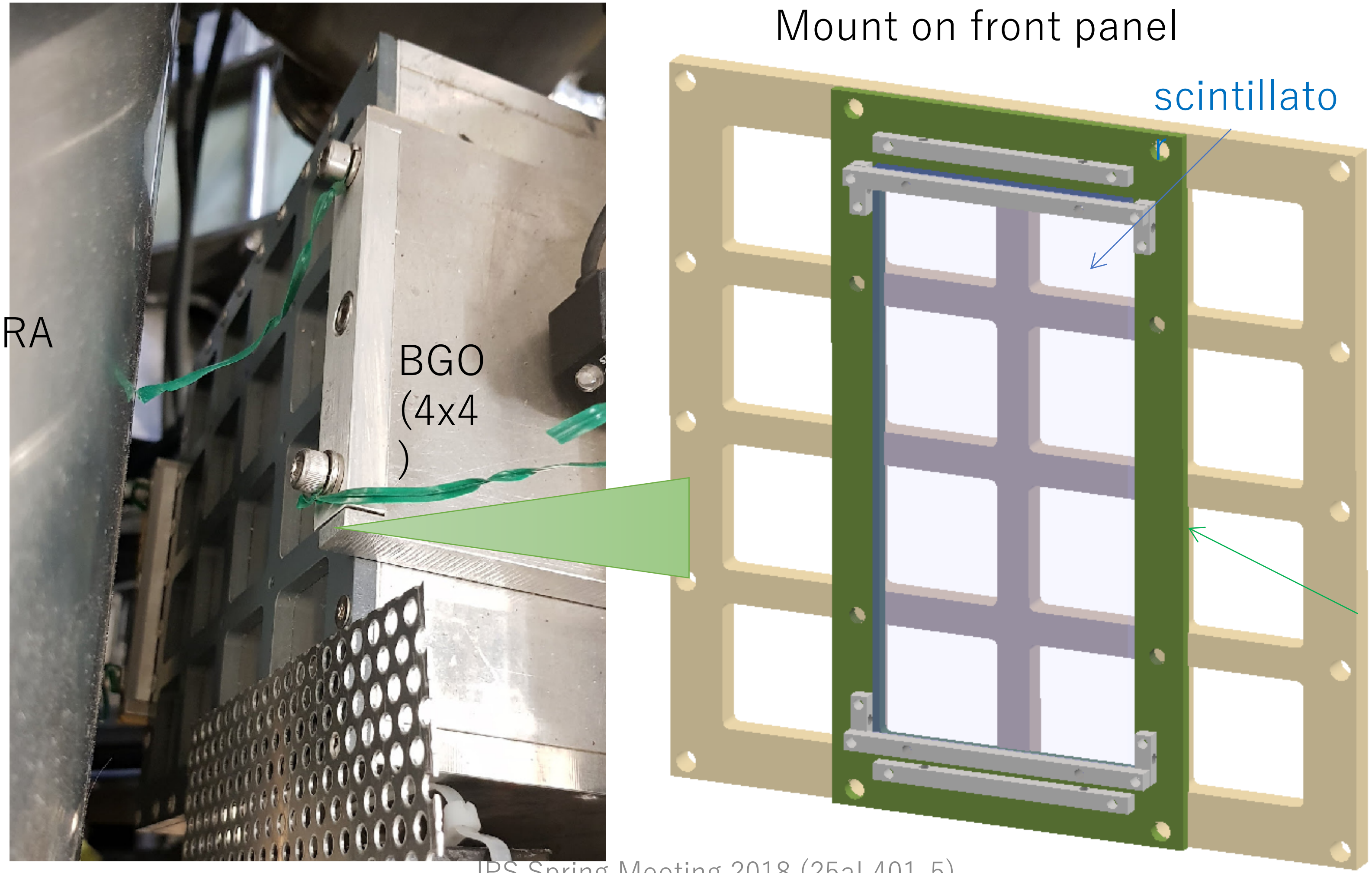


$46 \times 92 \times 5$ [mm^3]

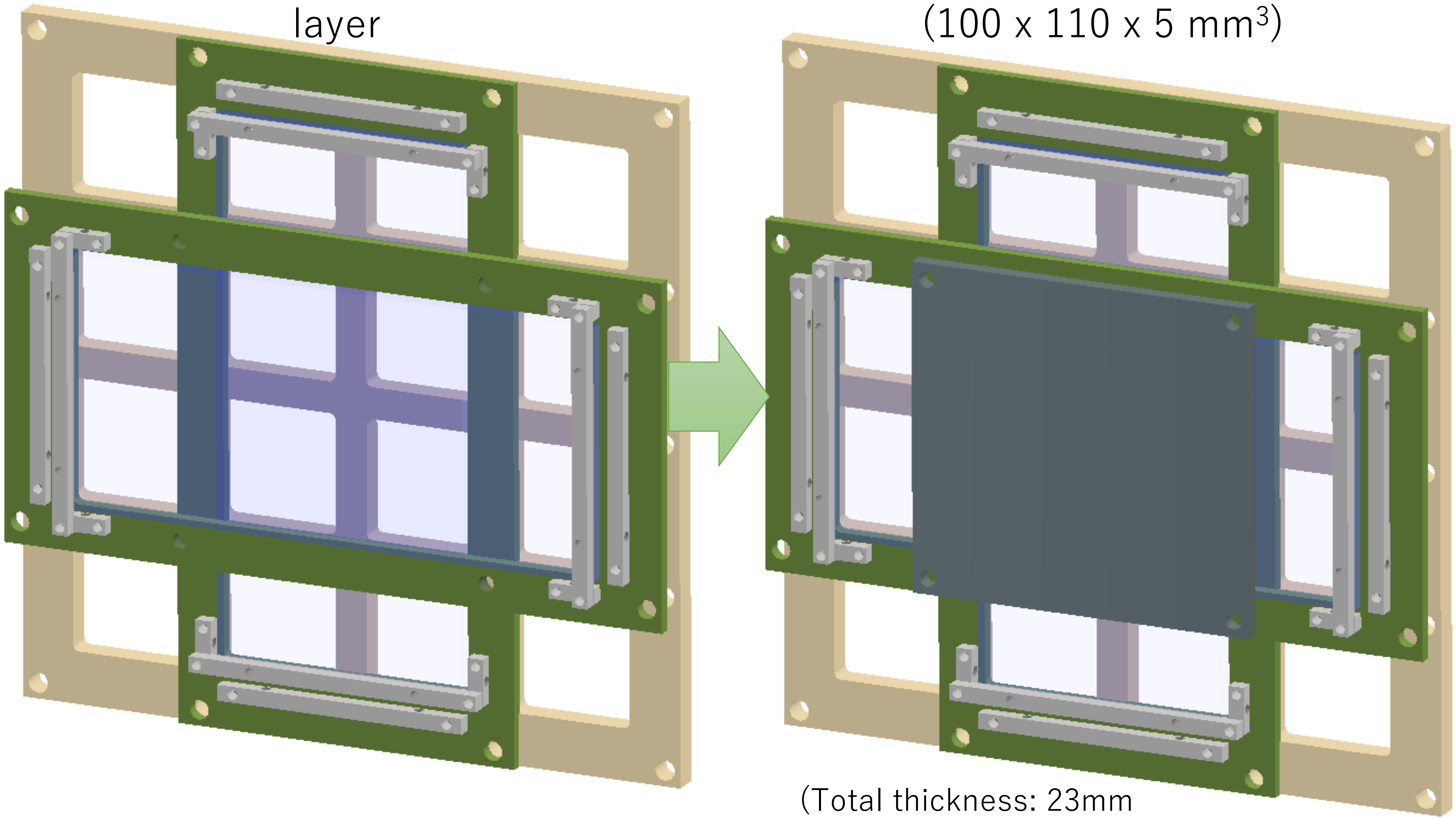


- If the width of scintillator is wider, the light yield difference among MPPCs is larger.
→Wider scintillator can have larger position dependence.

How to mount a scintillator



Two scintillator plates + lead plate



(Total thickness: 23mm
Gap between BGO and COBRA > 40mm)