

SiPM直列接続読み出しを用いる シンチレーション時間検出器の 放射線損傷による影響の評価

Study on the radiation damage effect on a scintillation timing counter with series-connected SiPMs readout

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日本物理学会第74回年次大会@九州大学



Core-to-Core Program

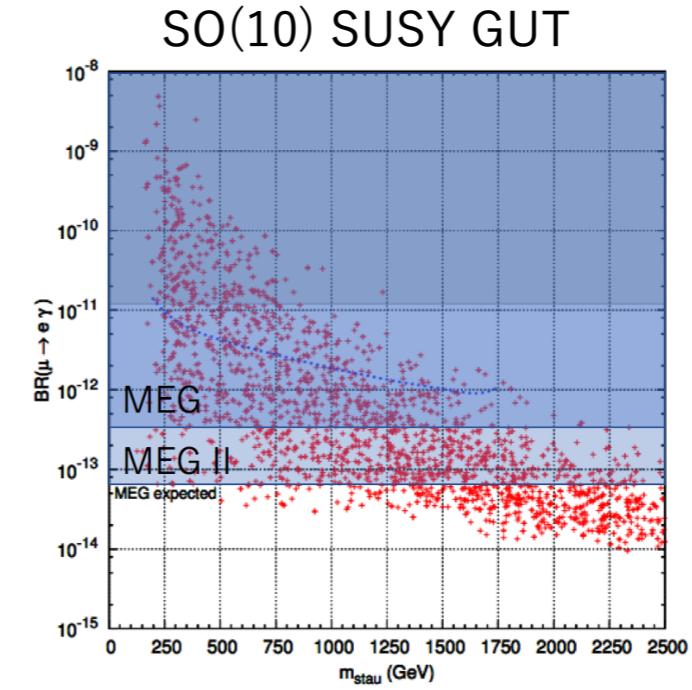
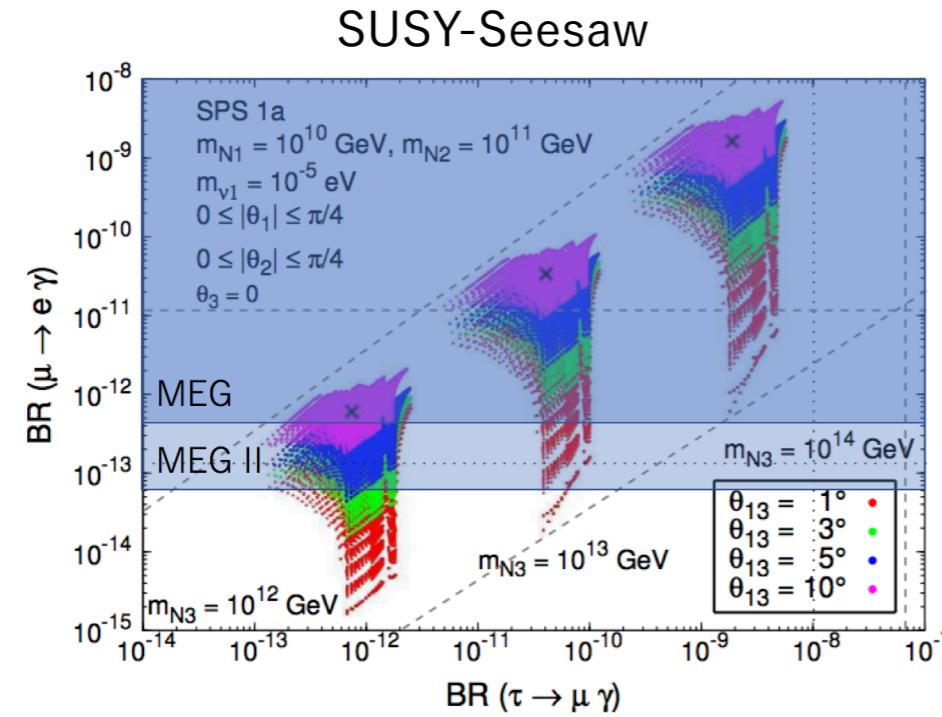


Introduction

- MEG II Experiment
- MEG II pixelated Timing Counter

MEG II: $\mu \rightarrow e \gamma$ decay search

- MEG II: $\mu \rightarrow e \gamma$ decay search experiment
 - One of the charged Lepton Flavor Violation phenomena.
 - **Prohibited in standard model**
 - **Predicted in beyond-standard models within experimental reach: $O(10^{-14} - 10^{-15})$**
- **To discover $\mu \rightarrow e \gamma$ means to discover the new physics!**



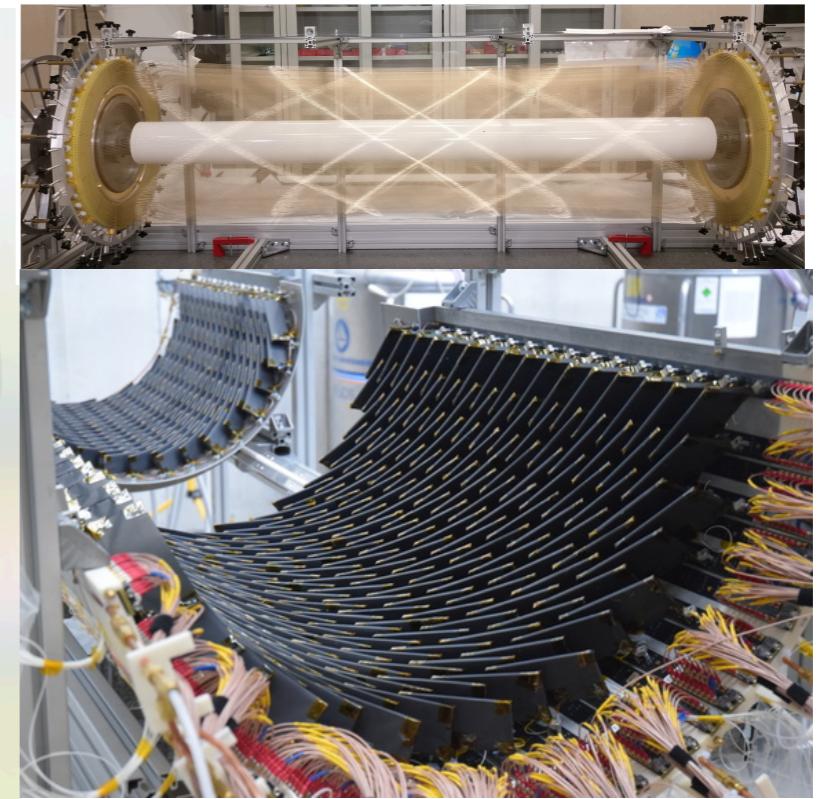
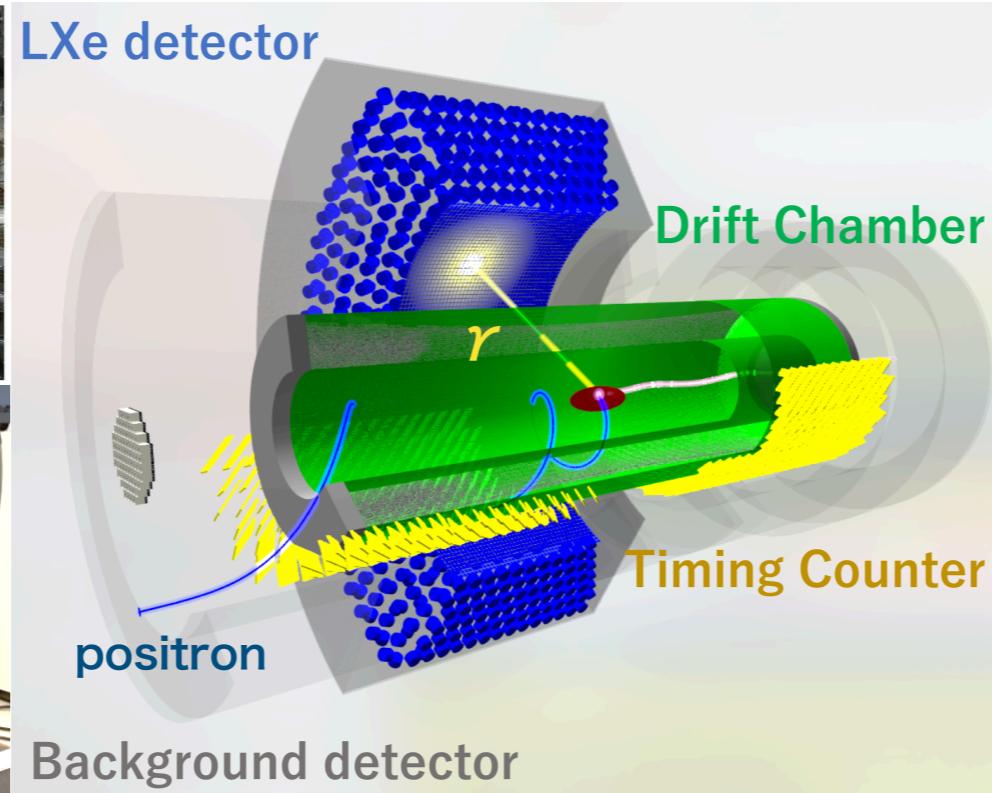
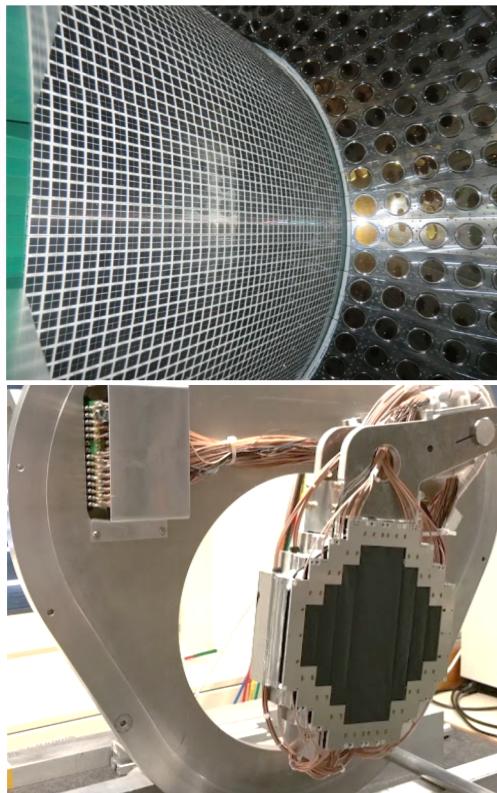
SUSY-Seesaw : S. Antusch et al. "Impact of θ_{13} on Lepton Flavour Violating processes within SUSY Seesaw" Journal of High Energy Physics 2006 (11), 090

SO(10) SUSY-GUT : Lorenzo Calibbi et al. "Flavour violation in supersymmetric SO(10) unification with a type II seesaw mechanism." JHEP, 0912:057, 2009.

にMEG、MEG IIの範囲を書き足して作成

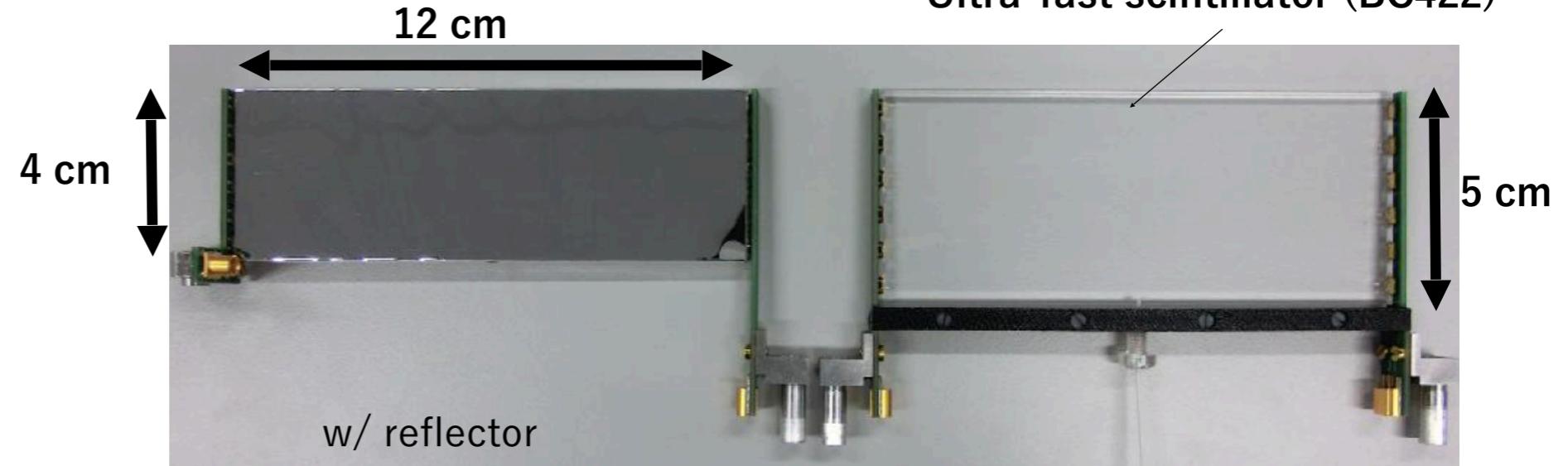
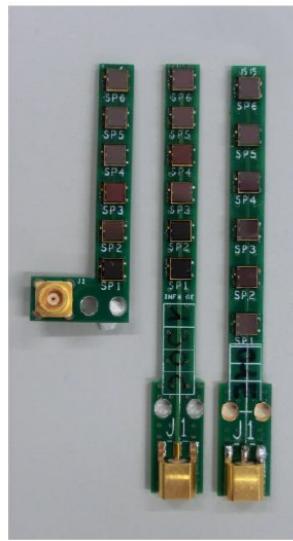
MEG II Experiment

- $\mu \rightarrow e \gamma$ decay search with the most intense DC muon beam ($7 \times 10^7 \mu/\text{s}$) at PSI, Switzerland
- Construction of all detectors are completed & commissioning 2018 was successfully finished with limited readout
 - Commissioning with full readout in the end of 2019
- Positron track is detected by Drift Chamber, positron timing is determined by pTC (pixelated-Timing Counter)



pixelated Timing Counter

6 SiPMs are connected in series

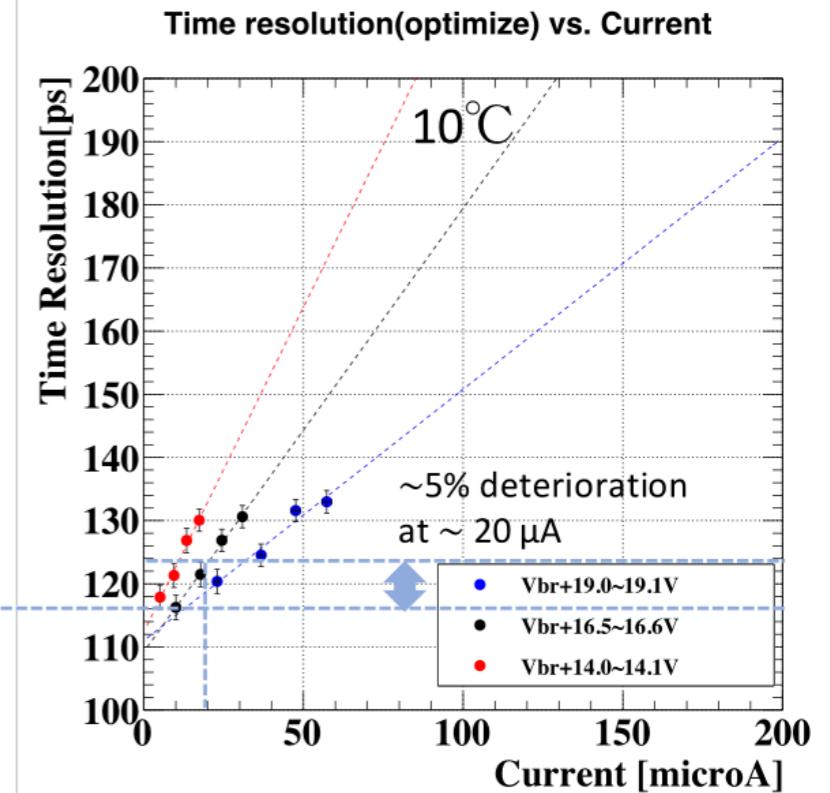
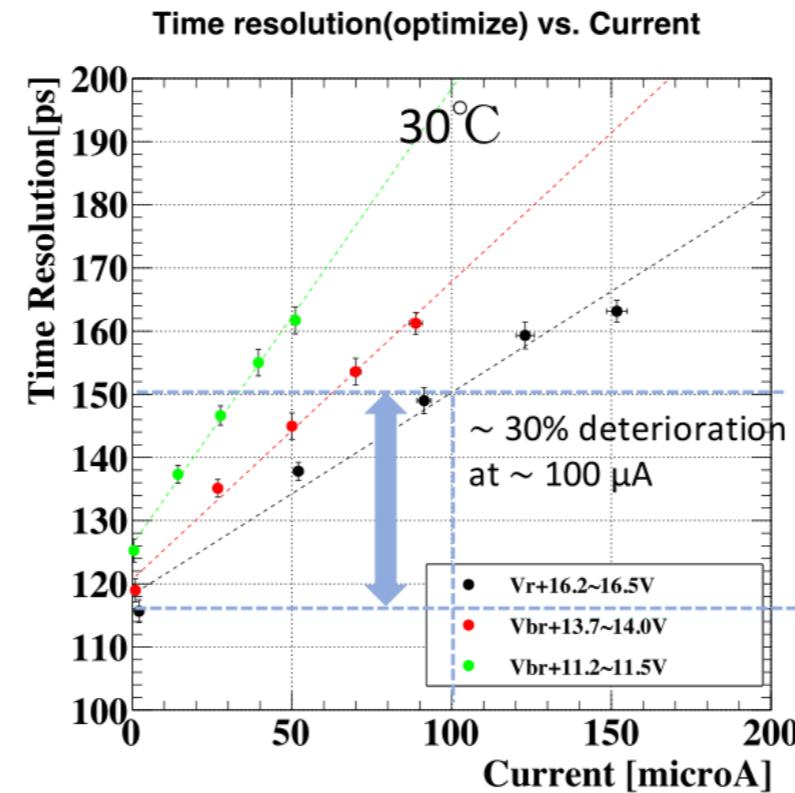
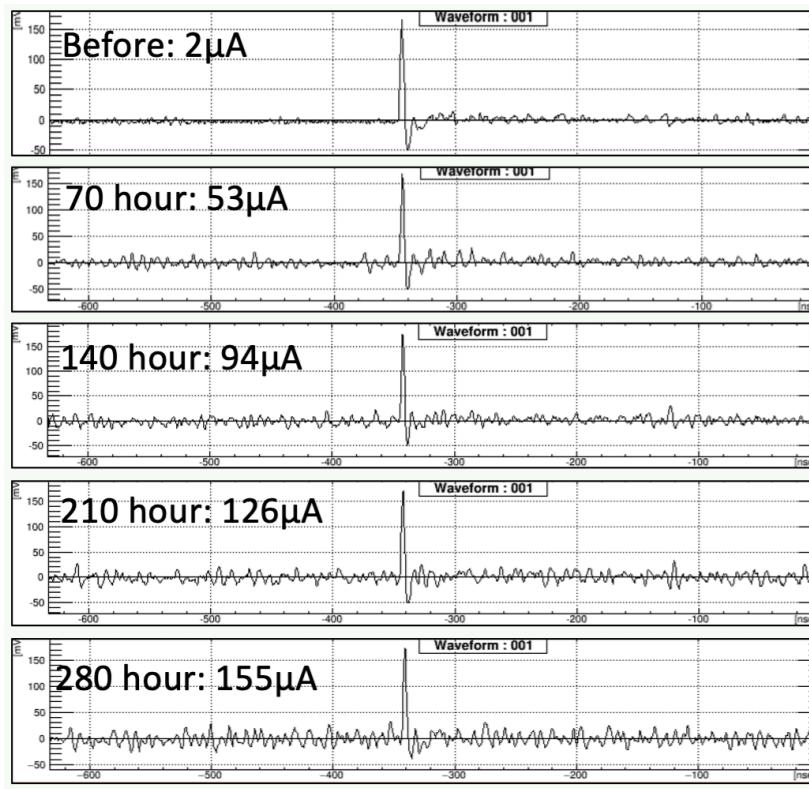


SiPM: ASD-NUV3S-P High-Gain(MEG) from AdvanSiD

- 512 small scintillation counter with series connected 6 SiPMs readouts at the both side
- Each counter has ~80 ps timing resolution, and using multi-hit information pTC achieves the target resolution: ~35 ps

Radiation damage

- MEG II experiment uses the intense muon beam, radiation damage on SiPMs was one of our concern
 - $7 \times 10^7 \mu\text{s}$, $\sim 110 \text{ kHz}$ positron hits at the each pixel
 - Current of each channel will reach from several μA to $\sim 100 \mu\text{A}$ around 30°C
- Dark noise increase deteriorate the timing resolution
 - Expected deterioration during MEG II data taking: $\sim 30\%$ at 30°C , $\sim 5\%$ at 10°C



※Timing pick up by constant fraction method

Series Connection

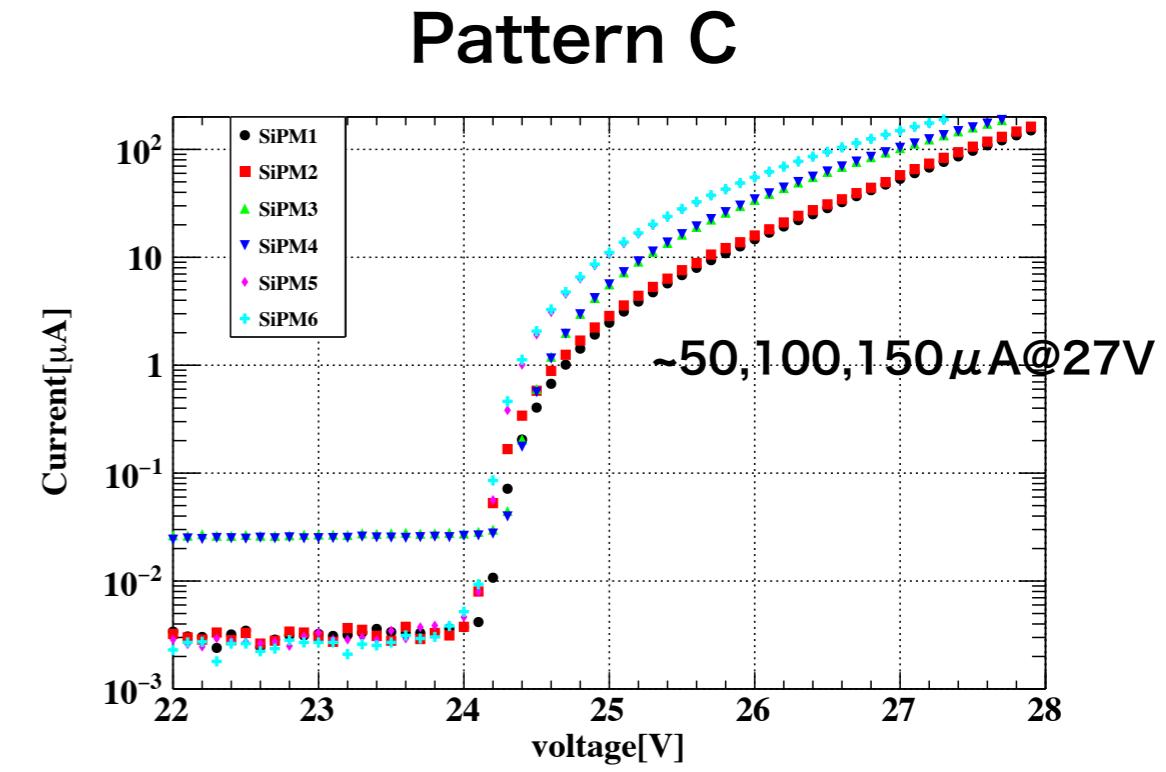
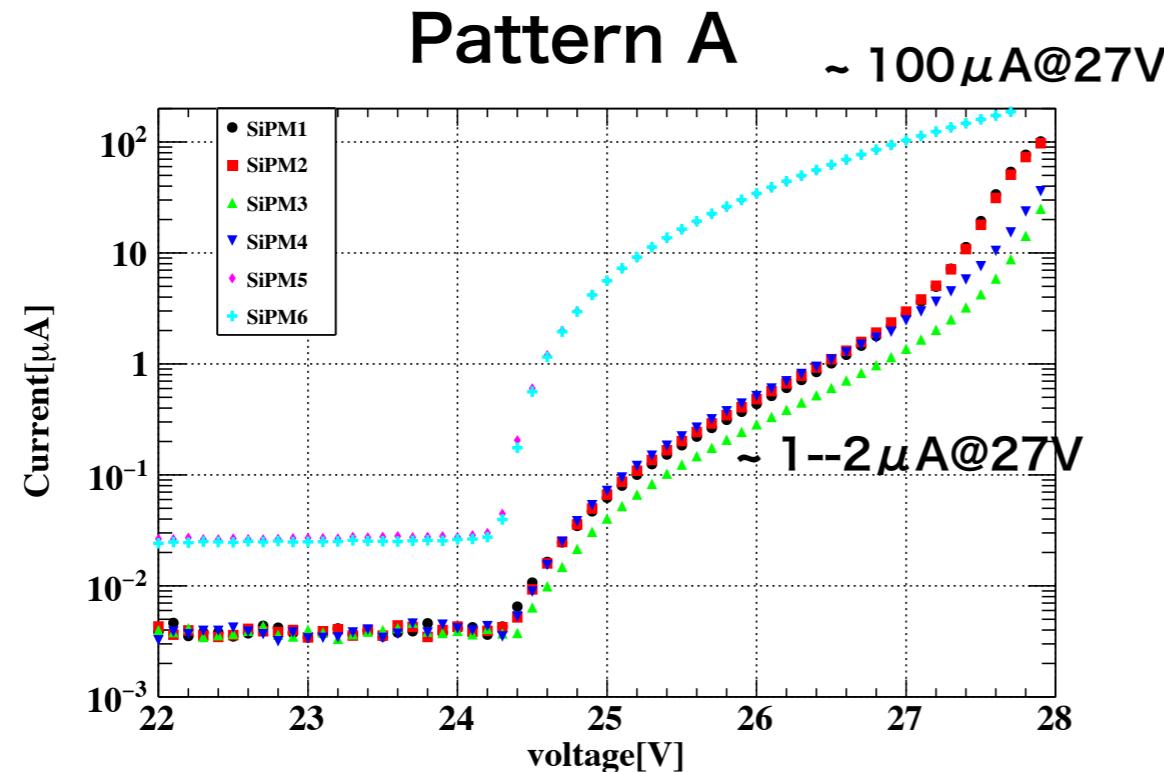
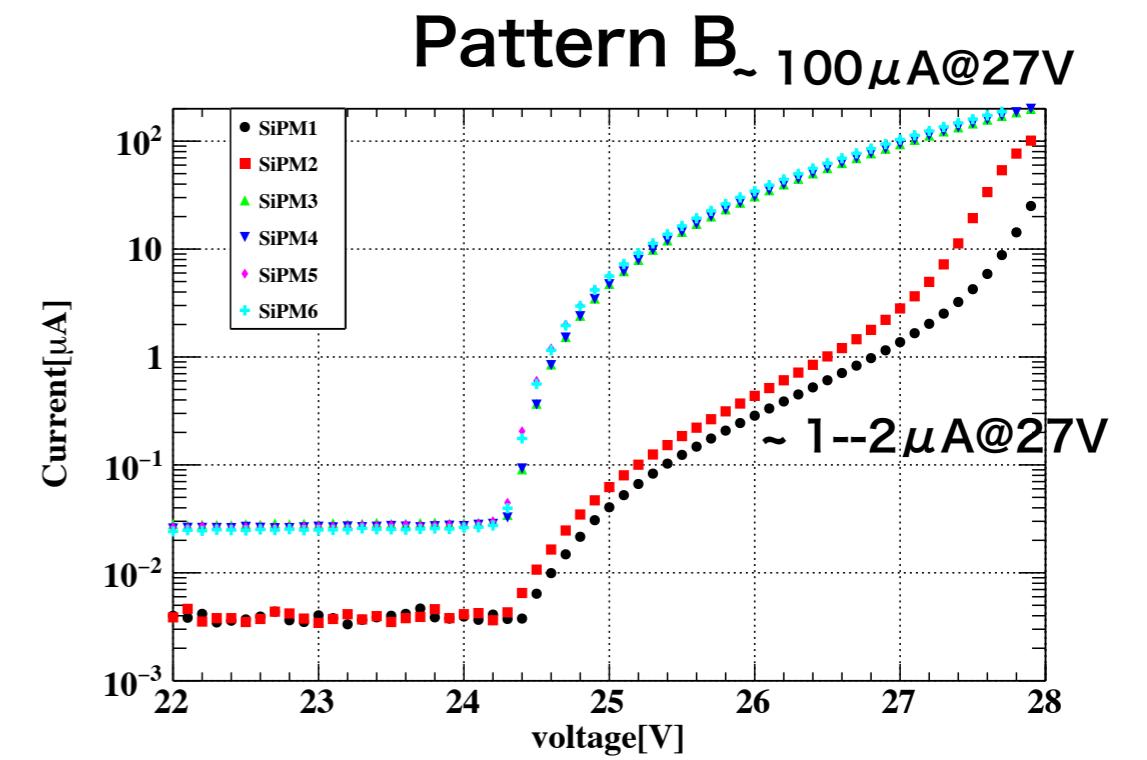
- We successfully understood the relationship b/w current increase (dark noise increase) and timing resolution. And we found its solution.
- **Yet another concern on series connection:** If we connect the differently damaged SiPMs in series, what will happen? How will it affect the counter performance?
 - Usually we connect the similar characteristic SiPMs
 - But the hit rate can be different in a counter b/w the top SiPM and the bottom SiPM under MEG II magnet field

Combination of SiPMs

- IV characteristics of SiPMs
- Breakdown voltage shift

Setups

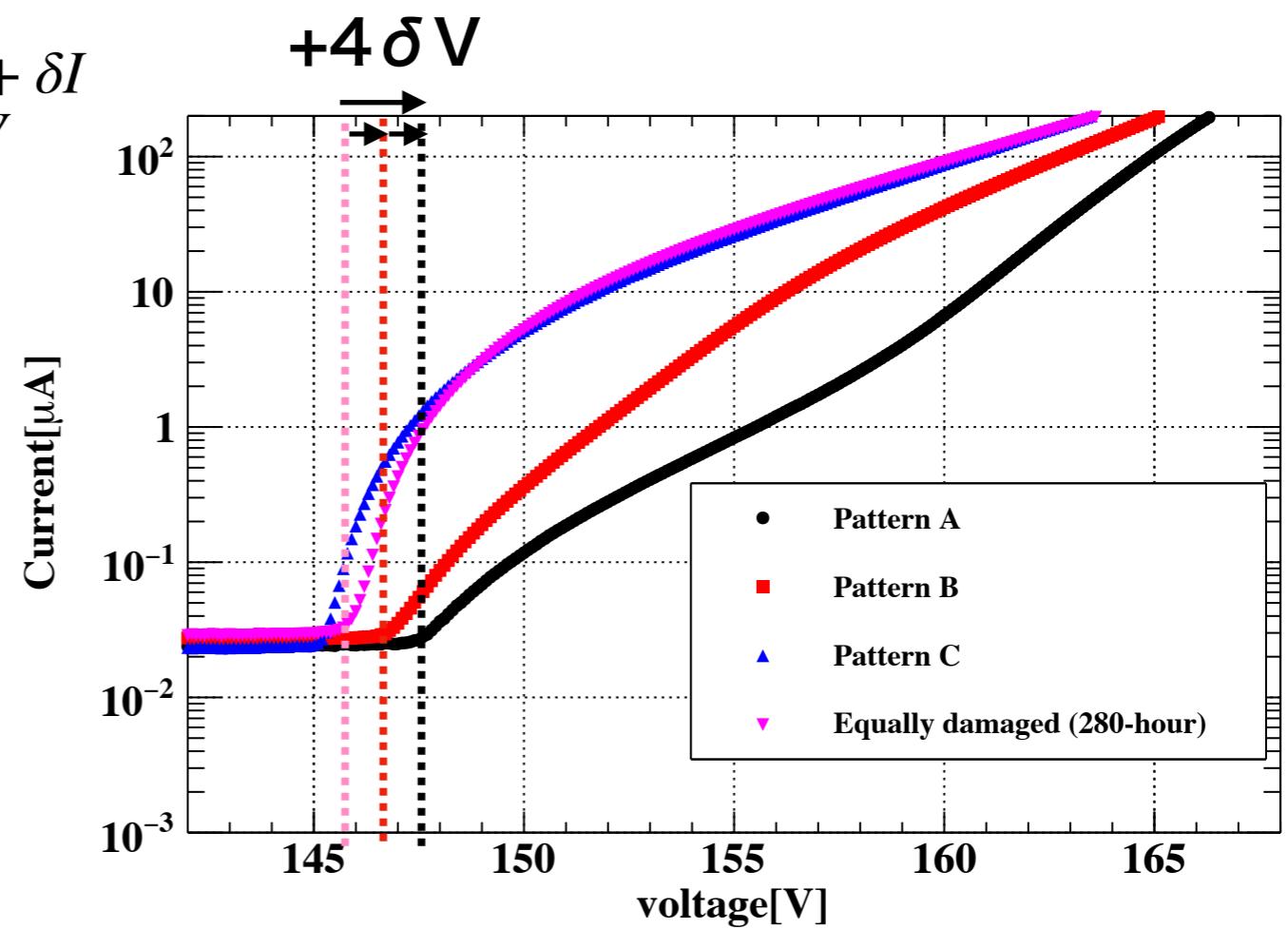
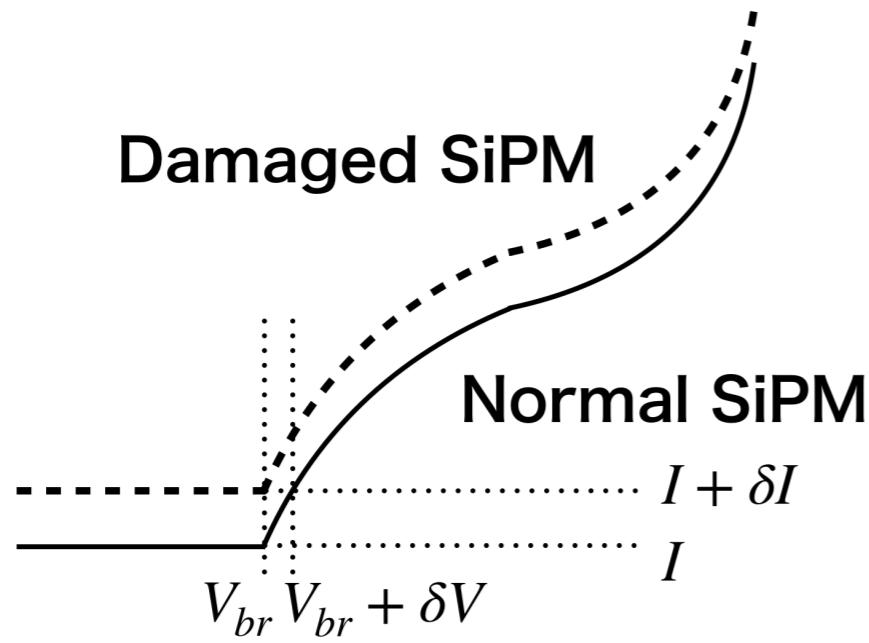
- 3 Patterns of combination
 - PatternA: 2 damaged SiPMs and 4 no damaged SiPMs
 - PatternB: 4 damaged SiPMs and 2 no damaged SiPMs
 - PatternC: All SiPMs are damaged by gradation



Breakdown voltage shift

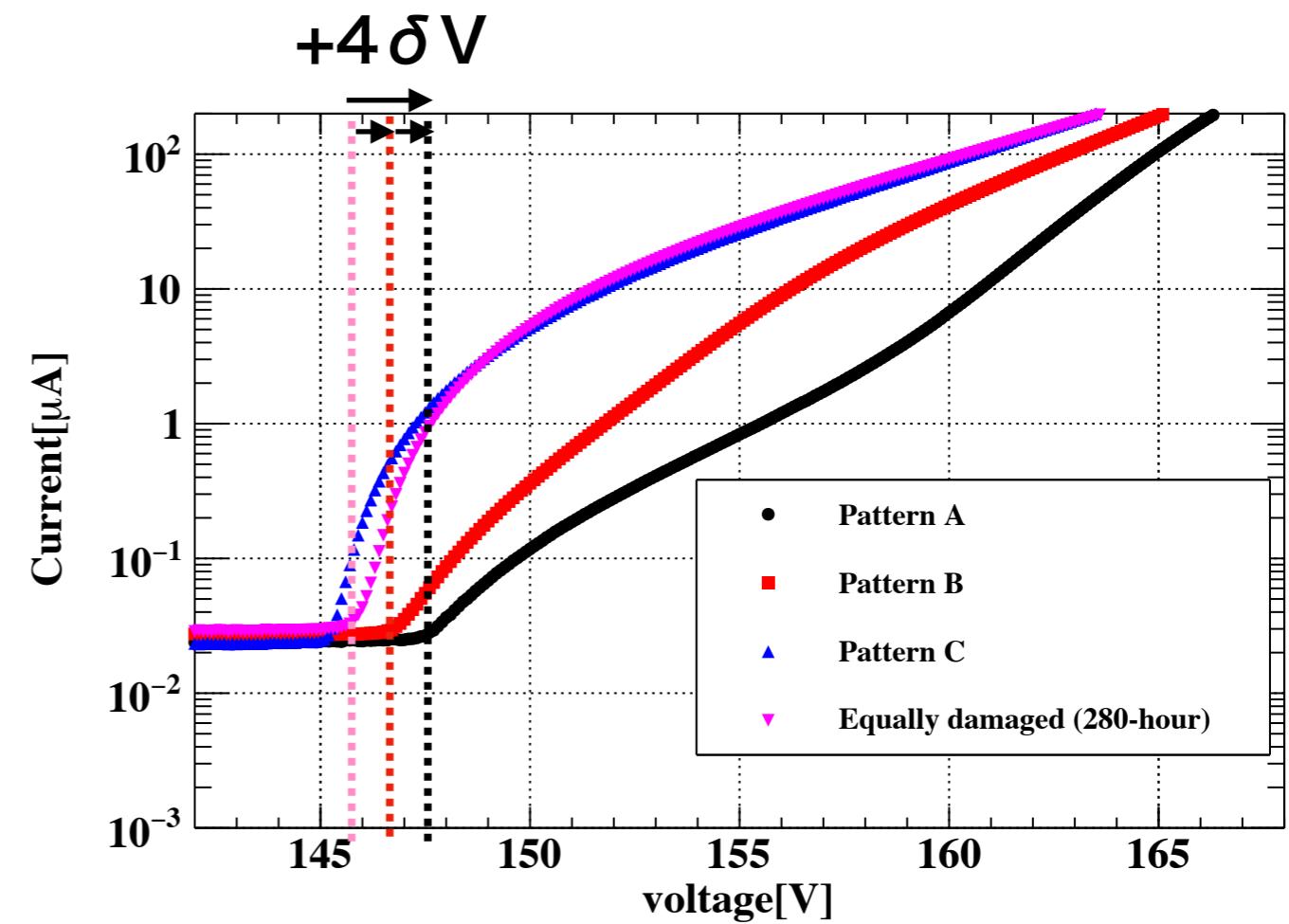
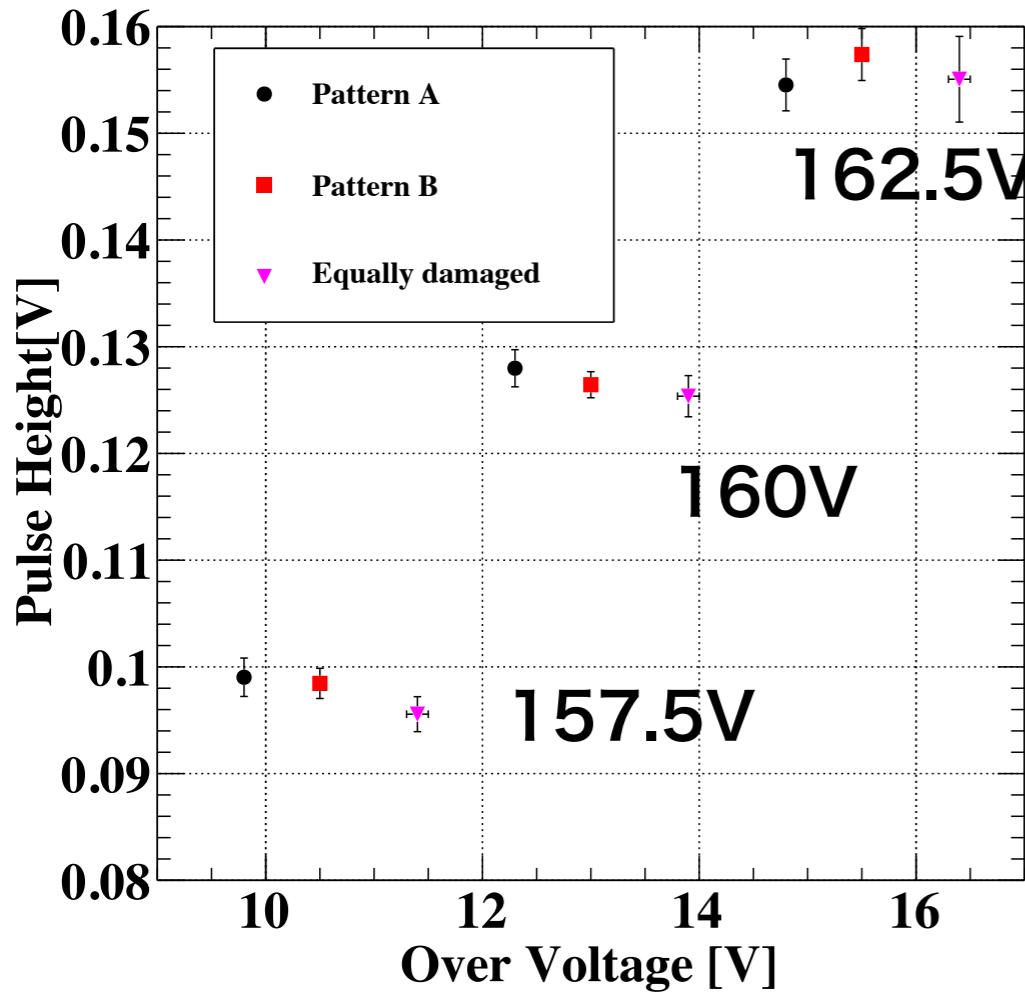
- Breakdown voltage shift was observed when connected in series
 - This effect can be explained by the difference among leak current of each SiPMs before breakdown voltage

Before breakdown: all SiPMs must have $I + \delta I$
 -> "apparent" breakdown voltage shift $+\delta V$



Breakdown voltage shift

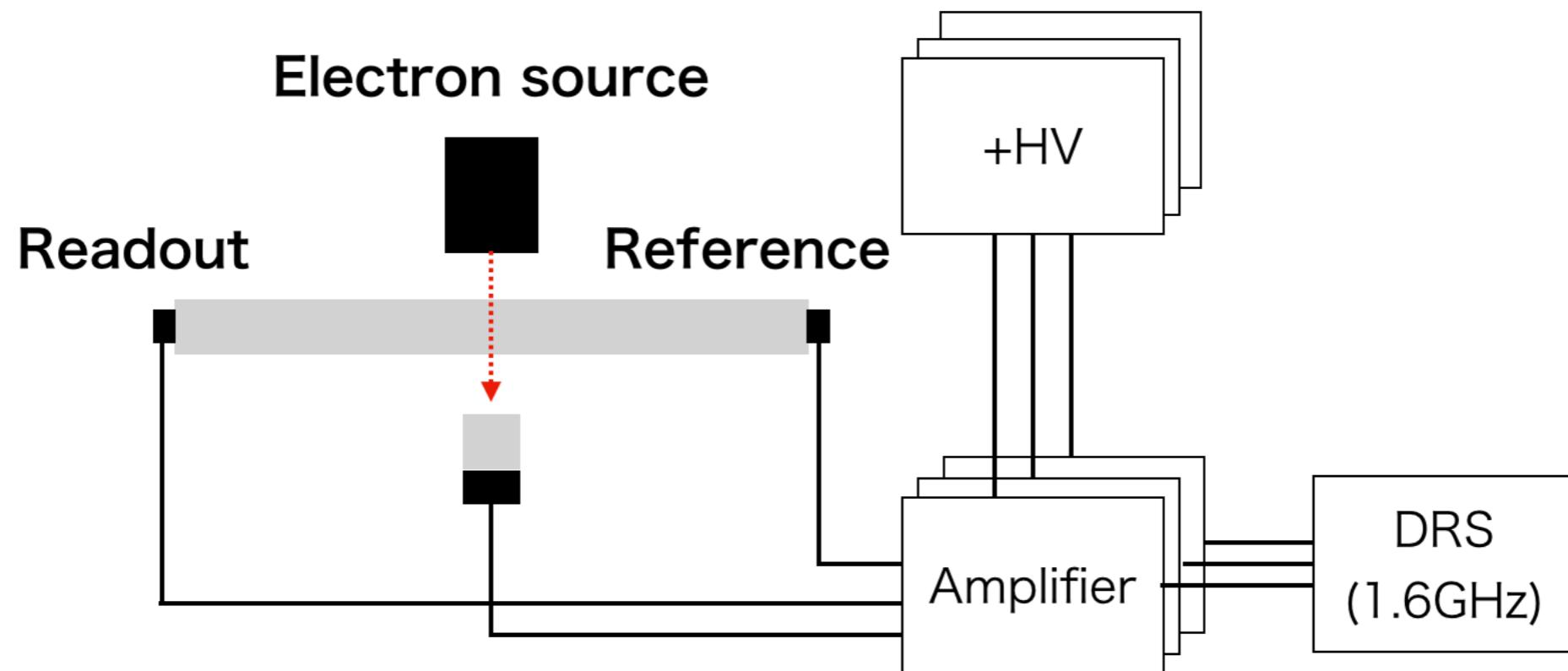
- Breakdown voltage shift was observed when connected in series
 - This effect can be explained by the difference among leak current of each SiPMs before breakdown voltage
 - This shift is "apparent". Effectively the V_{br} does not change.



Timing Measurement

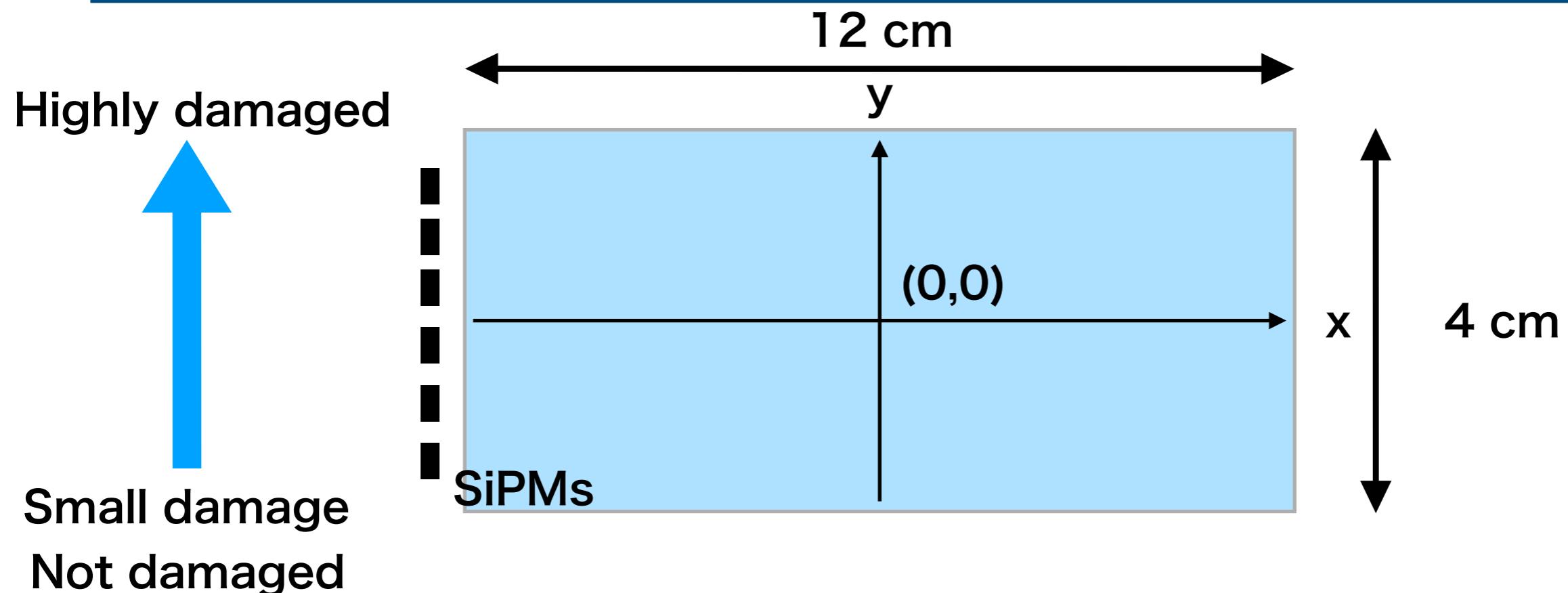
- Timing measurement setup
- Position scan in a counter

Timing Measurement

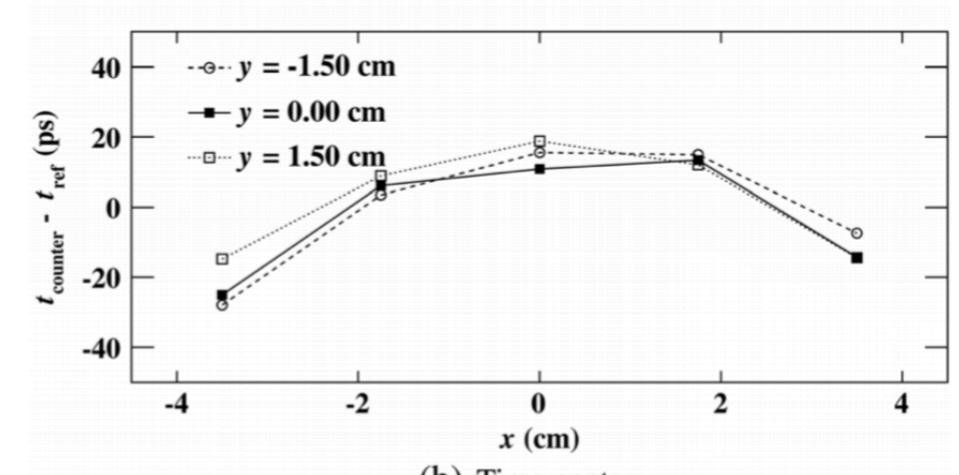


- Electron from the Sr90 source was illuminated on the counter, and the signal was read by the SiPMs attached on the side of scintillator.
- Trigger signal was made by the trigger counter
 - (5mm x 5mm x 5mm scintillator + SiPM)
- Waveform was recorded by Domino Ring Sampler chip (DRS) at 1.6 GHz sampling

Position Scan



- We checked the position dependence of pulse height and picked-up timing in a counter
- In previous study, there is no obvious dependence on height (y) direction.

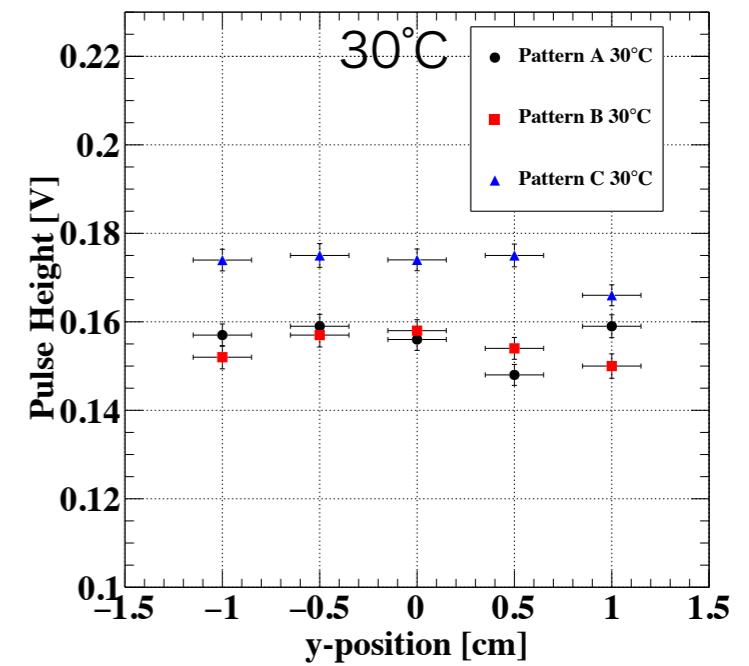
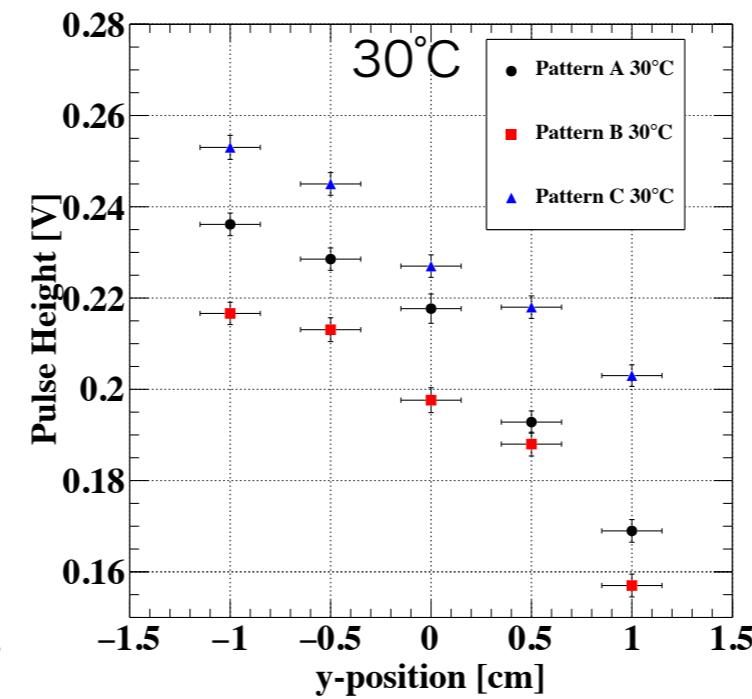
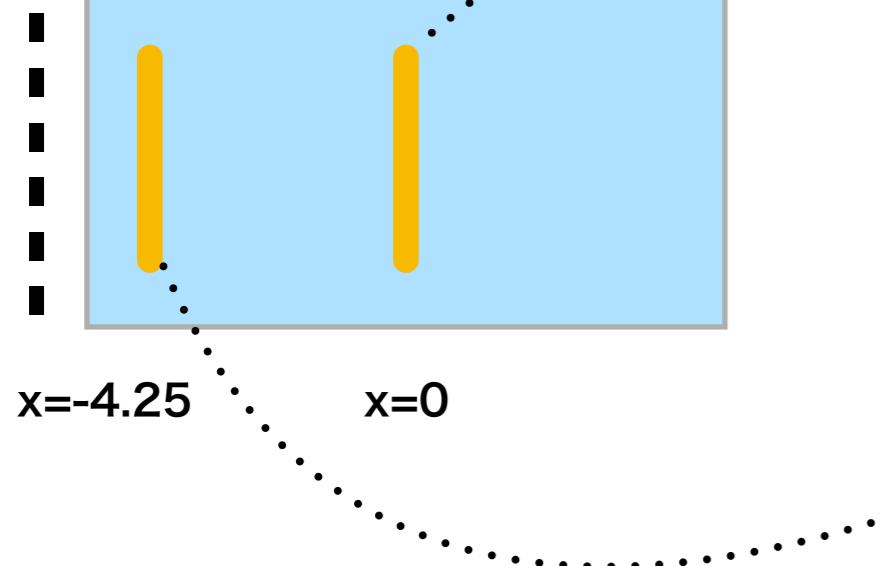


(b) Time center

P.W. Cattaneo et al, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 61, NO. 5, OCTOBER 2014 2657 - 2666

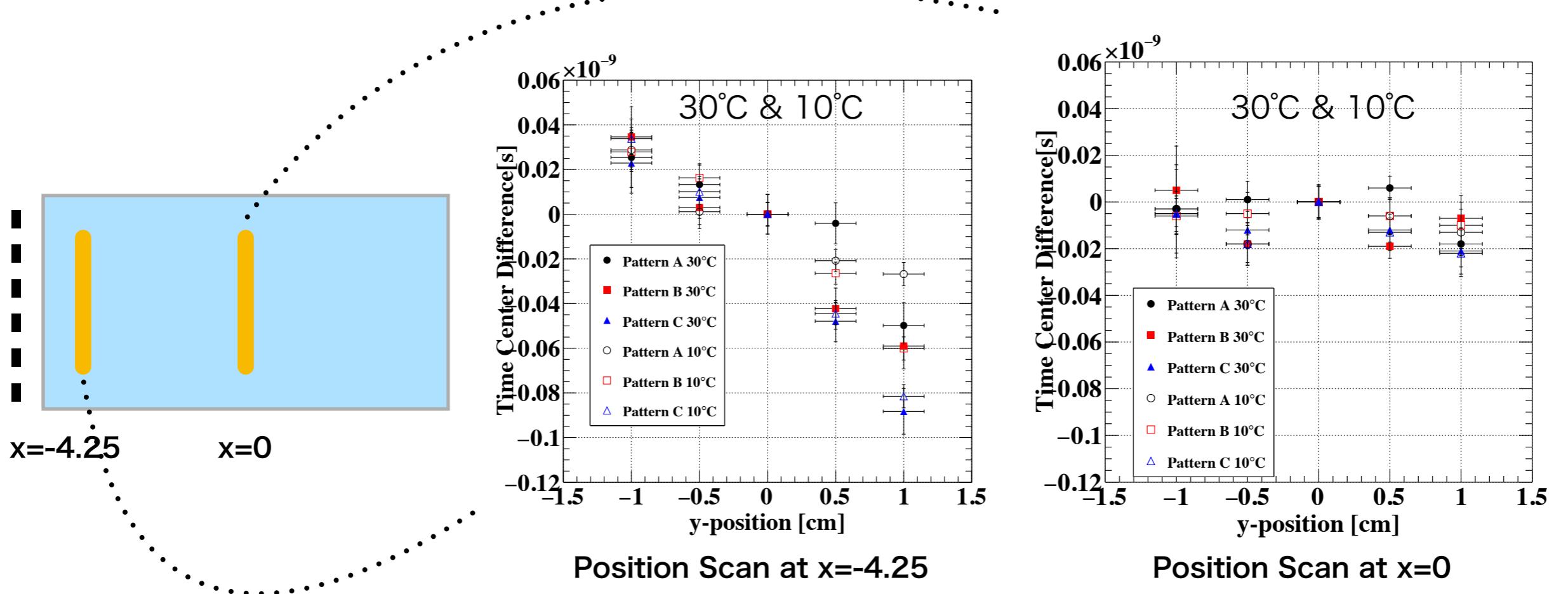
y-dependence of picked up timing
with no-damaged SiPMs

Pulse Height



- Position dependence of pulse height was observed at $x = -4.25$. When x became larger (far from the channel), this dependence vanished
 - Series connection: Current of all SiPMs must be the same
 - Over-voltage among SiPMs can be different \rightarrow Position dependence can arise

Time Center



- Position dependence of the mean value of the picked up timing
 - Time center: Mean ($t_{\text{signal}} - t_{\text{trigger}}$) of fixed constant fraction timing (20%)
- Clear dependence on height direction, additional $\sim 100\text{ps}$ deviation will arise.
- This cannot be recovered by cooling or multihit, but we can obtain the hit position by using drift chamber. \rightarrow Correction can be applied.

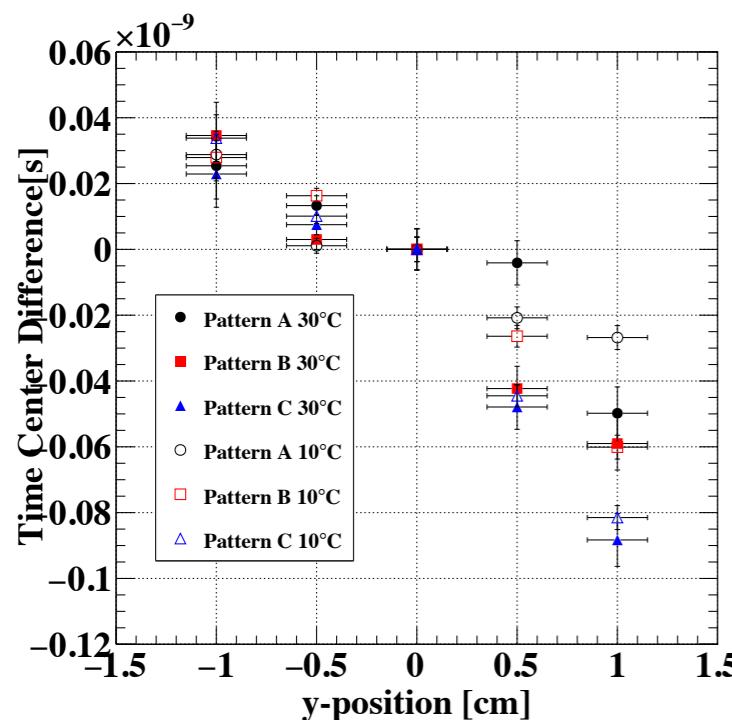
Summary

- We studied the radiation damage effect on series connected SiPMs
- Time resolution was deteriorated by dark noise increase. By cooling the deterioration and dark current were suppressed by a factor ~5
 - pTC was operated at 10°C setting during 2018 commissioning
- We also tested the series connection with differently-damaged SiPMs, and observed position dependence
 - Apparent V_{br} shift
 - Especially time center difference will cause the bias depending on the hit position near the channel (~100 ps).

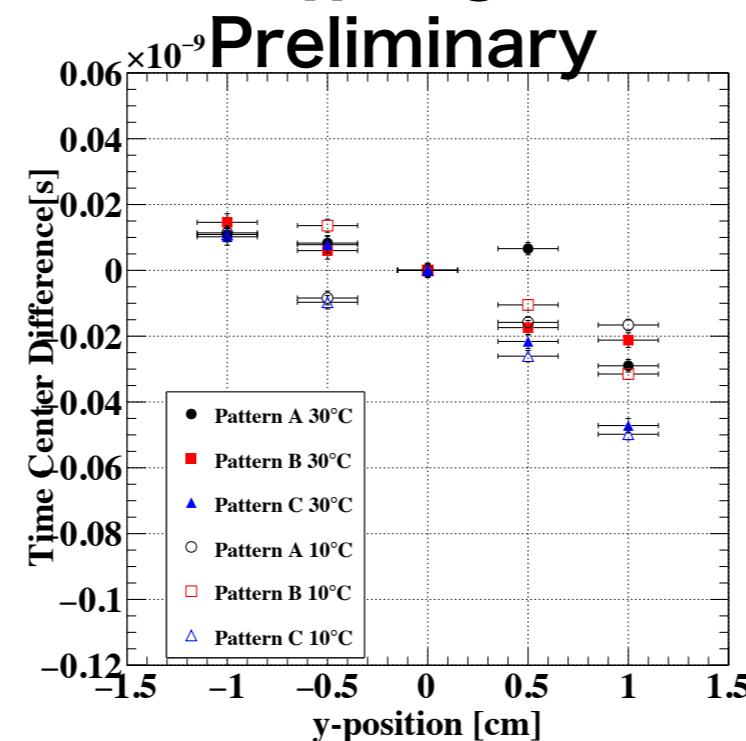
Backup

Time Center

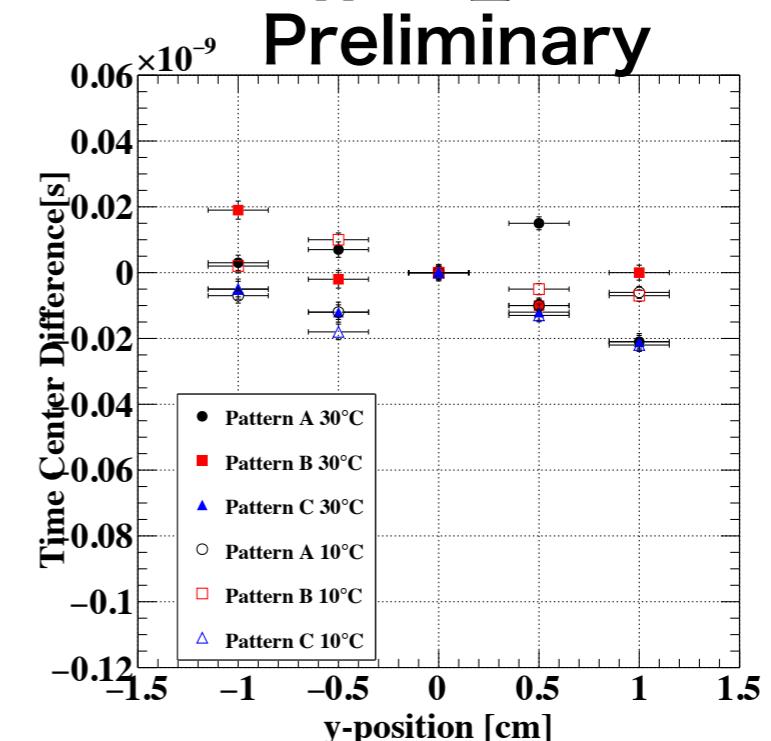
x = -4.25



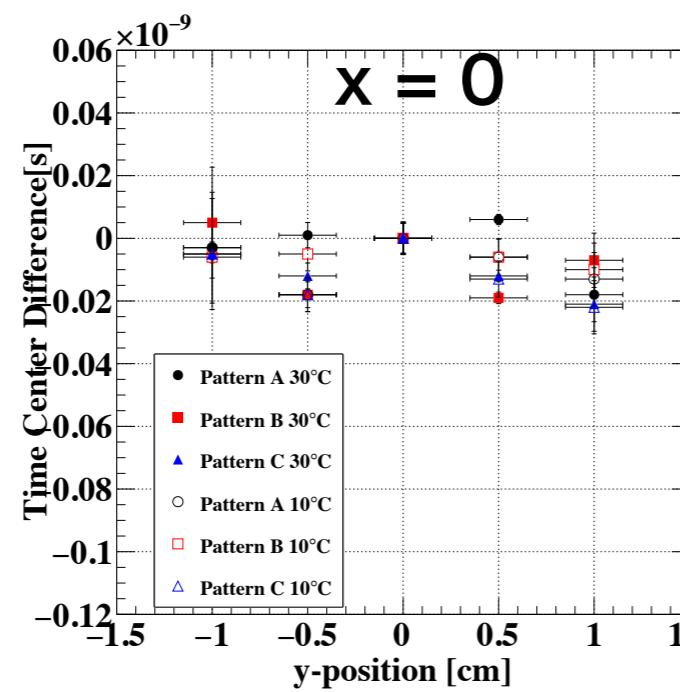
x = -3



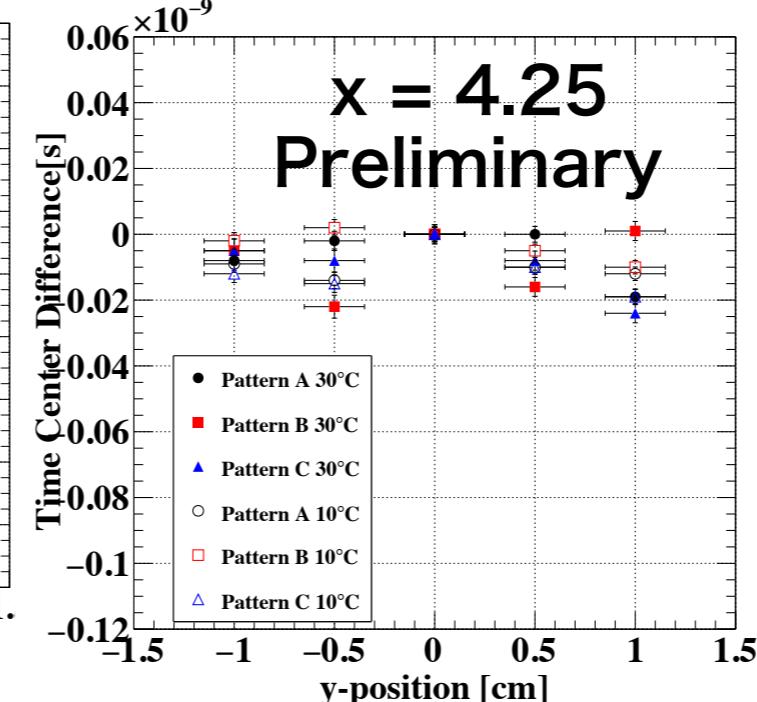
x = -2



x = 0



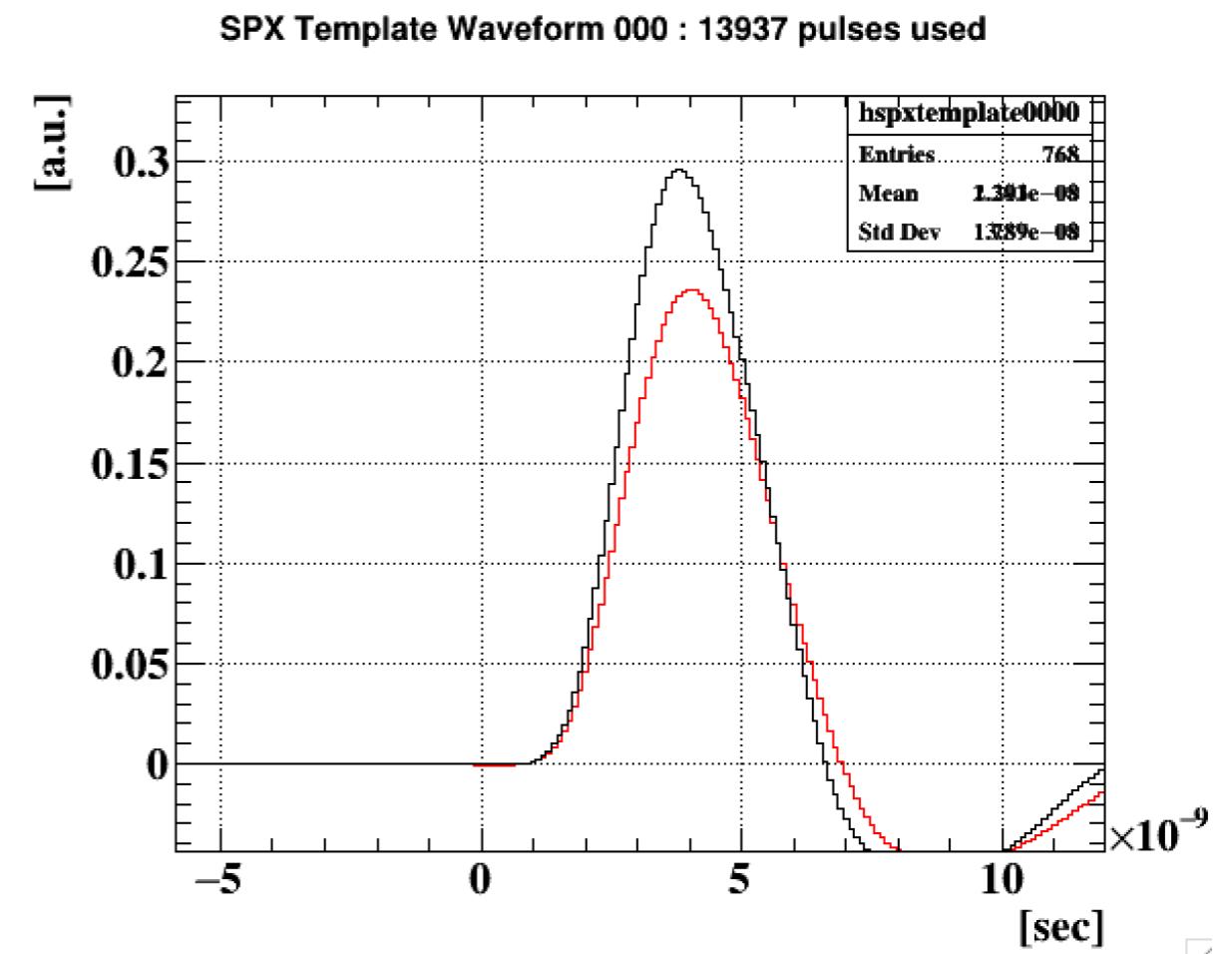
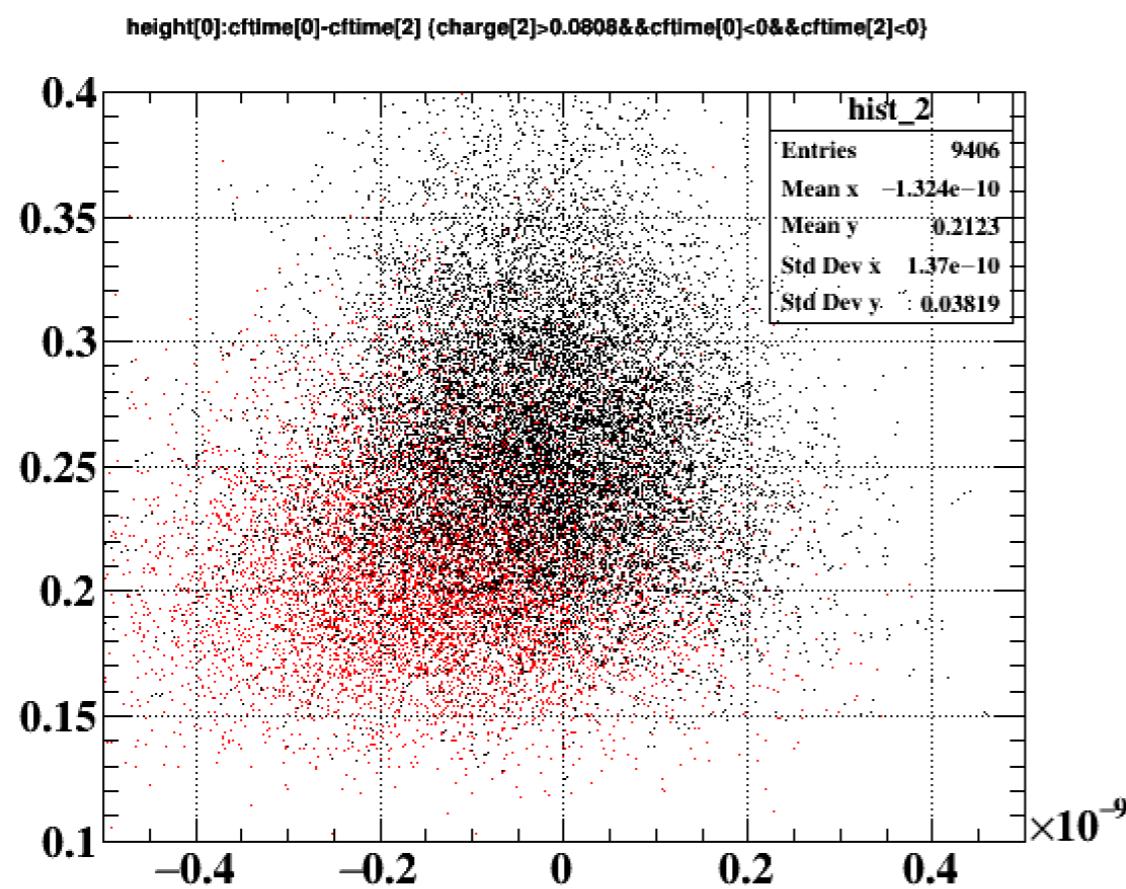
x = 4.25
Preliminary



Work in progress
&
Analysis ongoing!

Height vs. timing

Work in progress
&
Analysis ongoing!



Resolution

