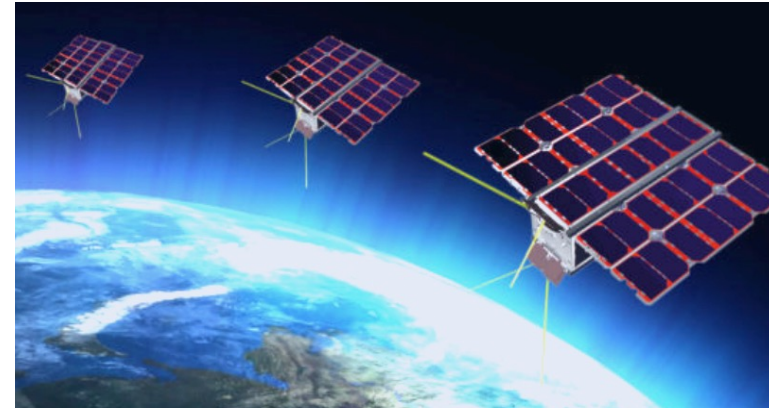


Annealing characteristic of  
Hamamatsu MPPCs (Si-  
PMs) after keeping in room  
temperature and after  
baking

Hiroto Matake, Hiromitsu Takahashi, Ryo Imazawa  
(Hiroshima University)

# Why we study Si-PMs?

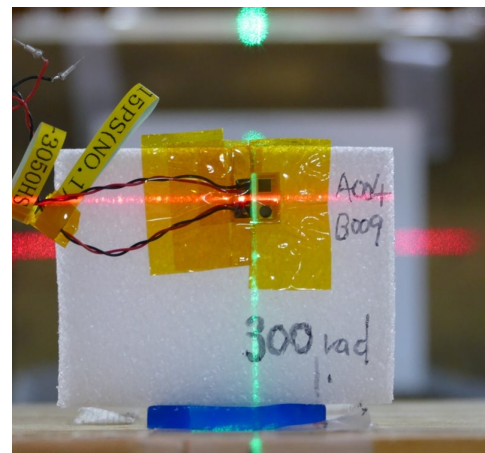
- We are studying Hamamatsu MPPCs (Multi Pixel Photon Counter) for CAMELOT.
- We are studying performance of irradiated MPPCs with 200 MeV proton beams for space operation.
- We will report 2 results of annealing.



CAMELOT



The wakasa-wan Energy Research center



Irradiated MPPCs



## Annealing 1

Kept in 20 °C  
for 7 months



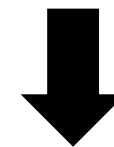
## Annealing 2

Backed at 150 °C  
for 3 hours

# MPPCs presented @this workshop

MPPCs	Irradiation date (2018)	Irradiation date (2019)	Irradiation date (2020)
S14160-3015PS			✓
S14160-3050HS			✓
S14160-6050CS		✓	
S14420-3050 MOD			✓
S14160-3050 MOD			✓
S13360-6050CS	✓		

I will present

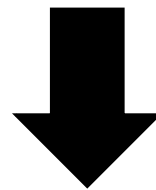


Imazawa's talk

## After kept in room temperature

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MPPCs	Irradiation date (2018)	Irradiation date (2019)	Irradiation date (2020)
S14160-3015PS			✓
S14160-3050HS			✓
S14160-6050CS		✓	
S14420-3050 MOD			✓
S14160-3050 MOD			✓
S13360-6050CS	✓		



Annealing after kept in room temperature

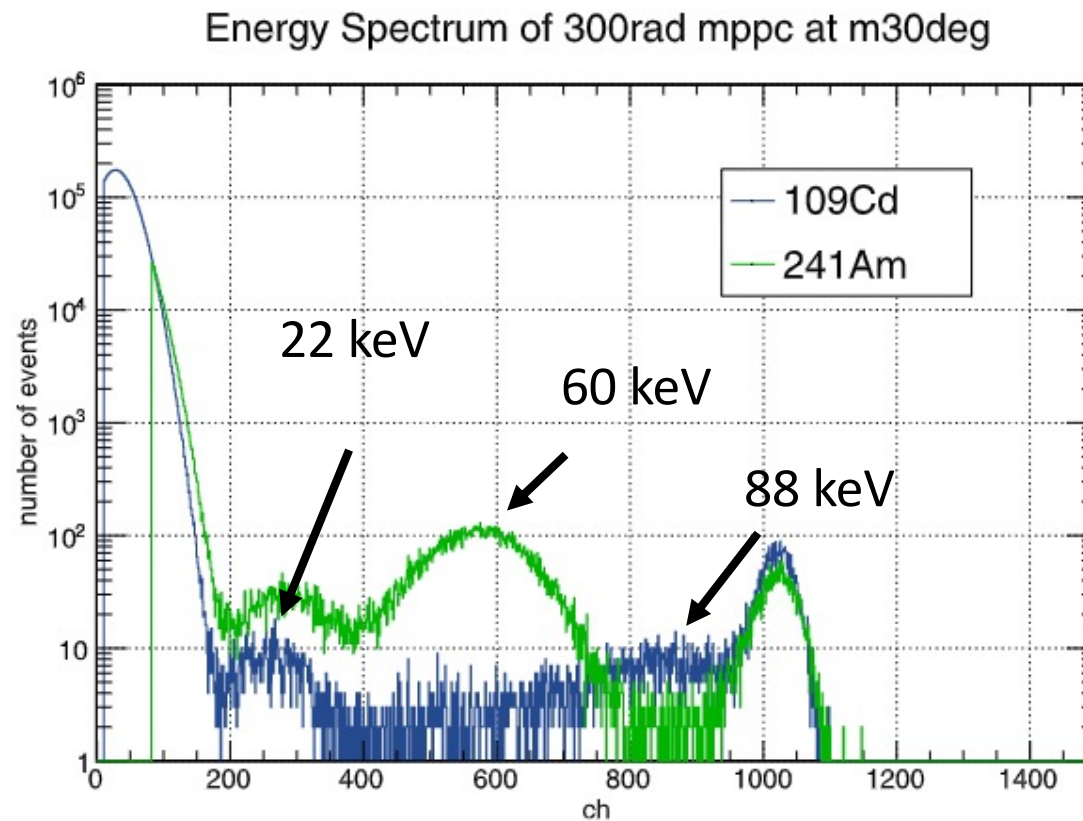
# After kept in room temperature

S14160-6050CS



4

CsI (Ti)



At one month after irradiation, a comparison of the spectra shows annealing had occurred.

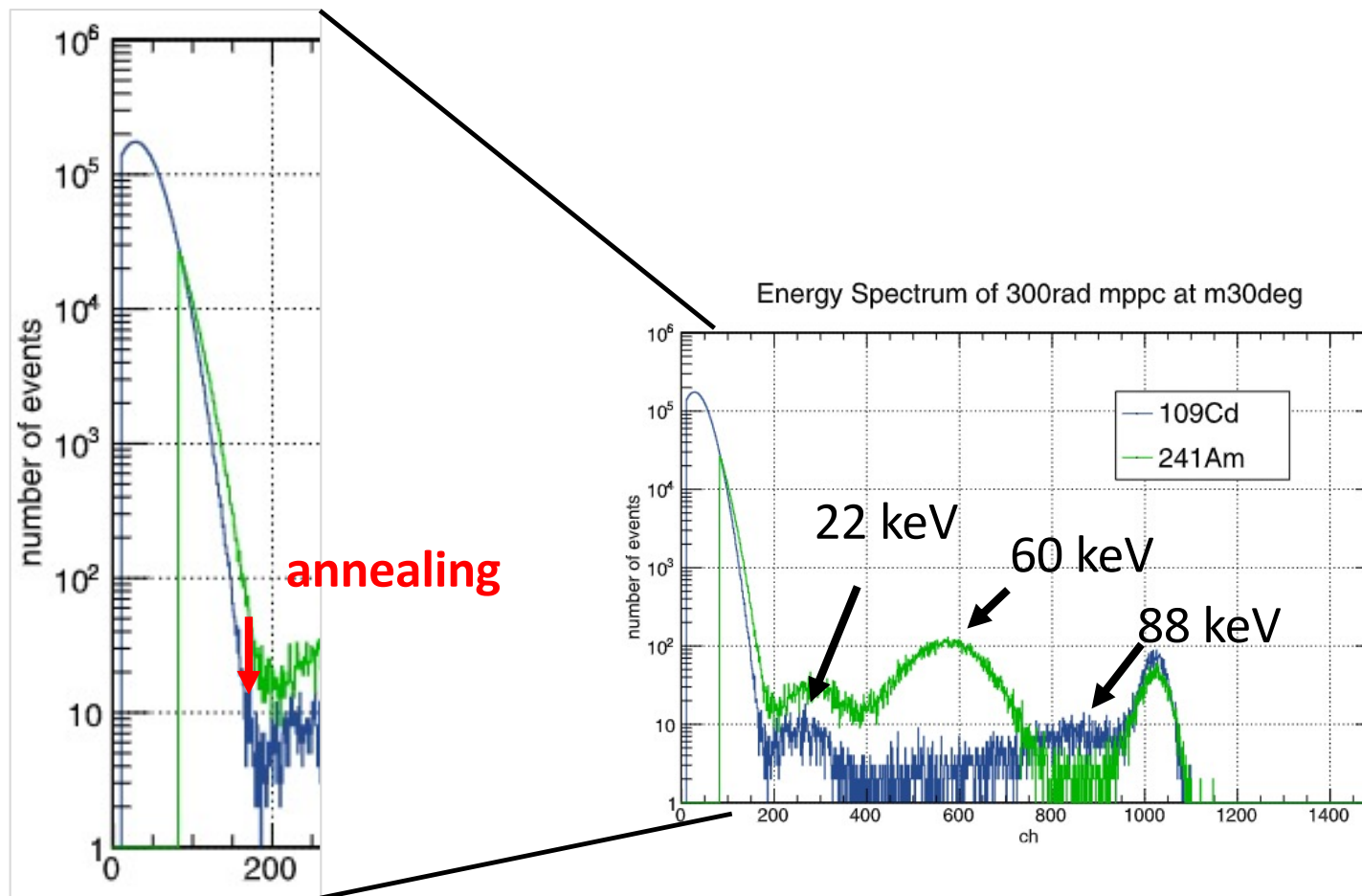
# After kept in room temperature



4

S14160-6050CS

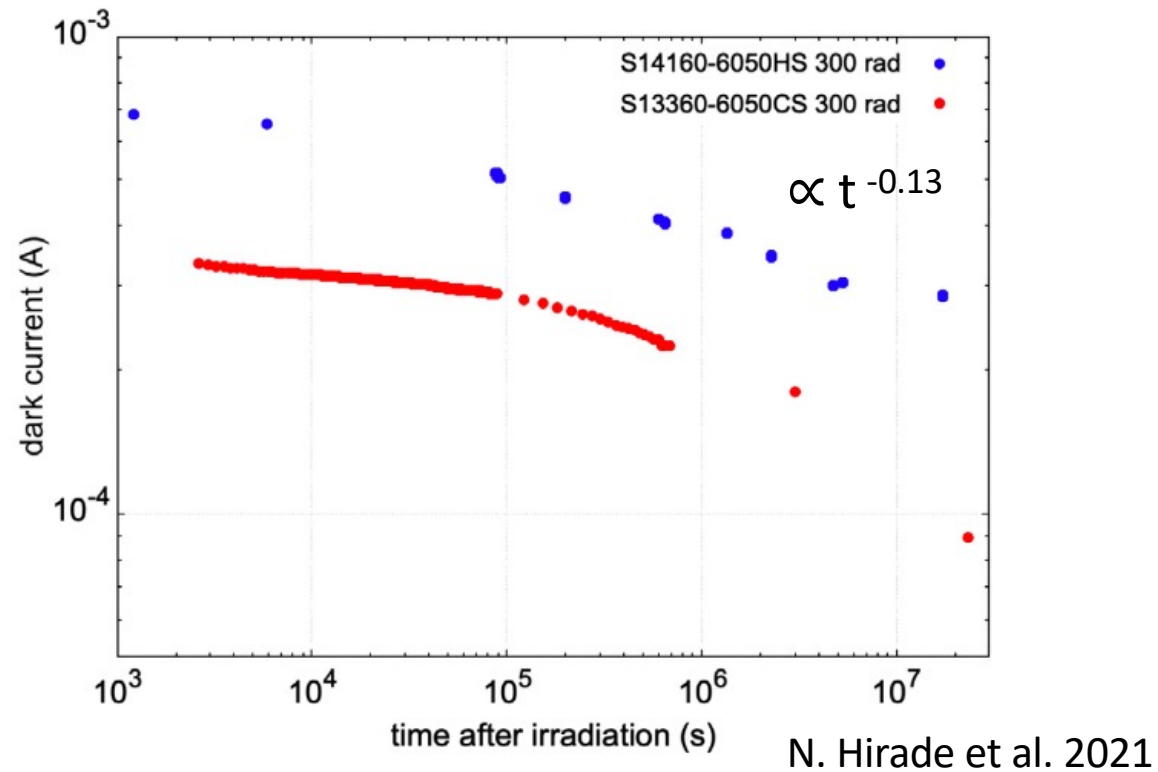
CsI (Ti)



At one month after irradiation, a comparison of the spectra shows annealing had occurred.

# After kept in room temperature

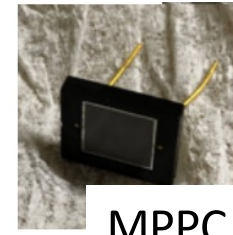
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The dark current was also confirmed to go down.

# After kept in room temperature

S13360-6050CS



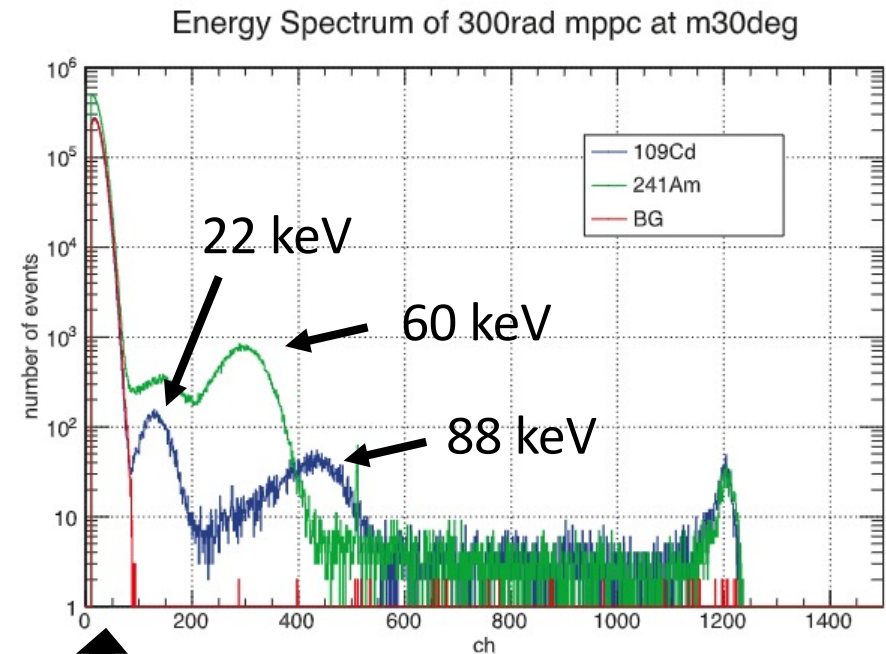
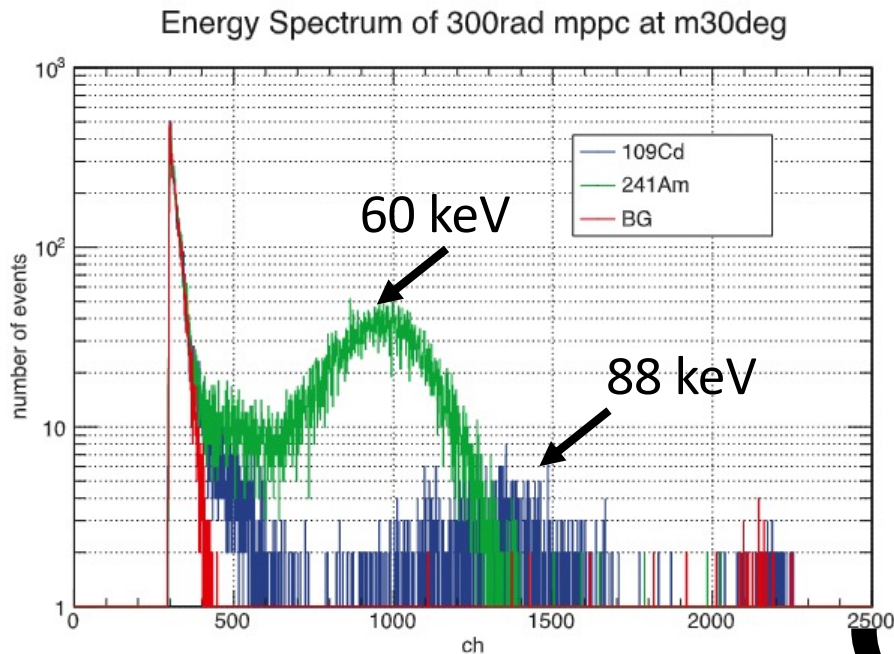
MPPC



CsI (Ti)

6

We used a MPPC irradiated with 300 rad at  $-30\text{ }^{\circ}\text{C}$ .



After 7 months

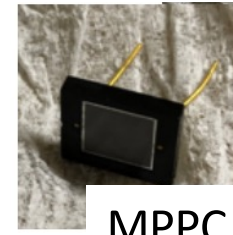
N. Hirade et al. 2021

We can see a sub peak of  $^{109}\text{Cd}$  at 22.2 keV.  
We think S13360-6050CS is annealed.



# After kept in room temperature

S13360-6050CS



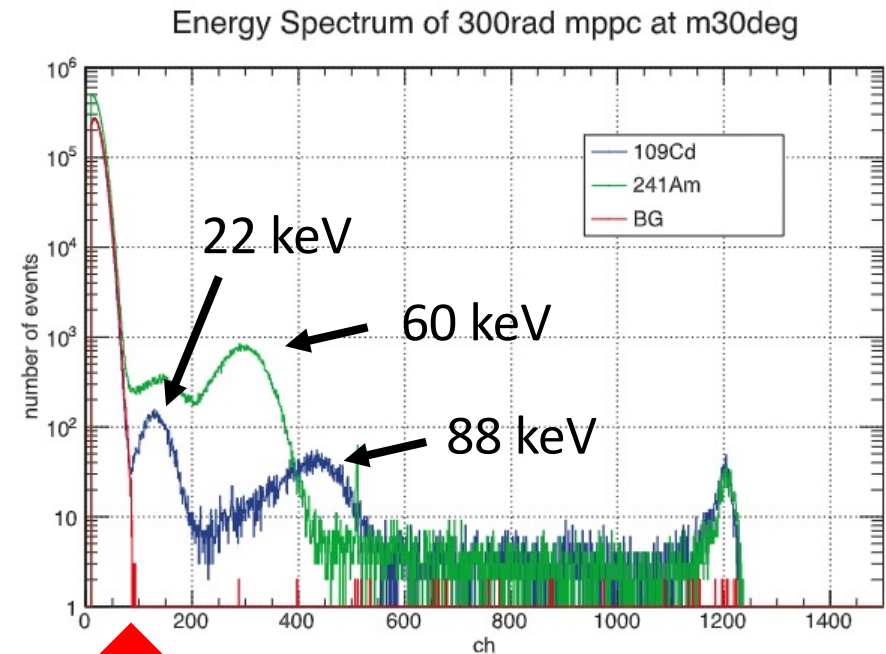
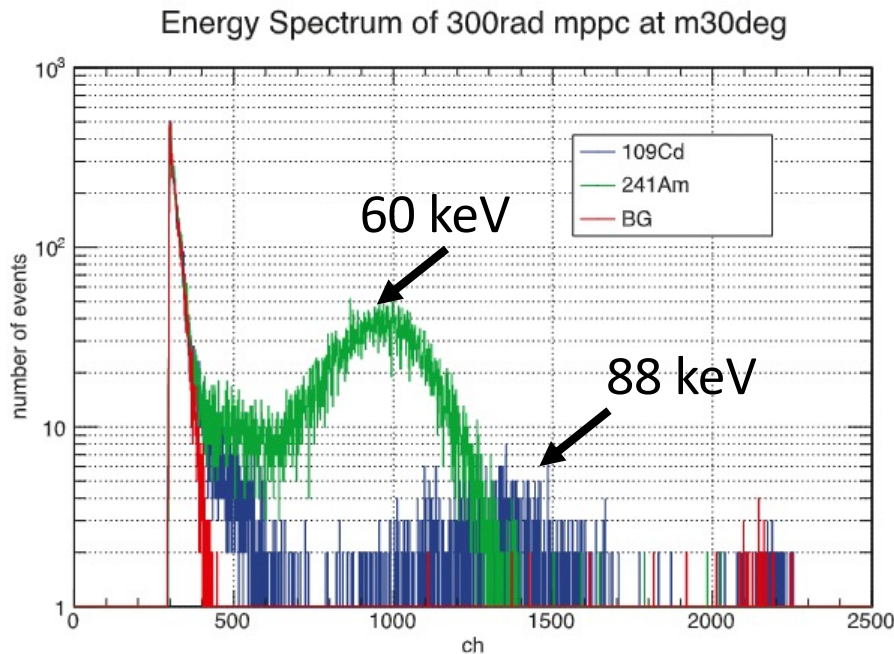
MPPC



CsI (Ti)

6

We used a MPPC irradiated with 300 rad at  $-30\text{ }^{\circ}\text{C}$ .



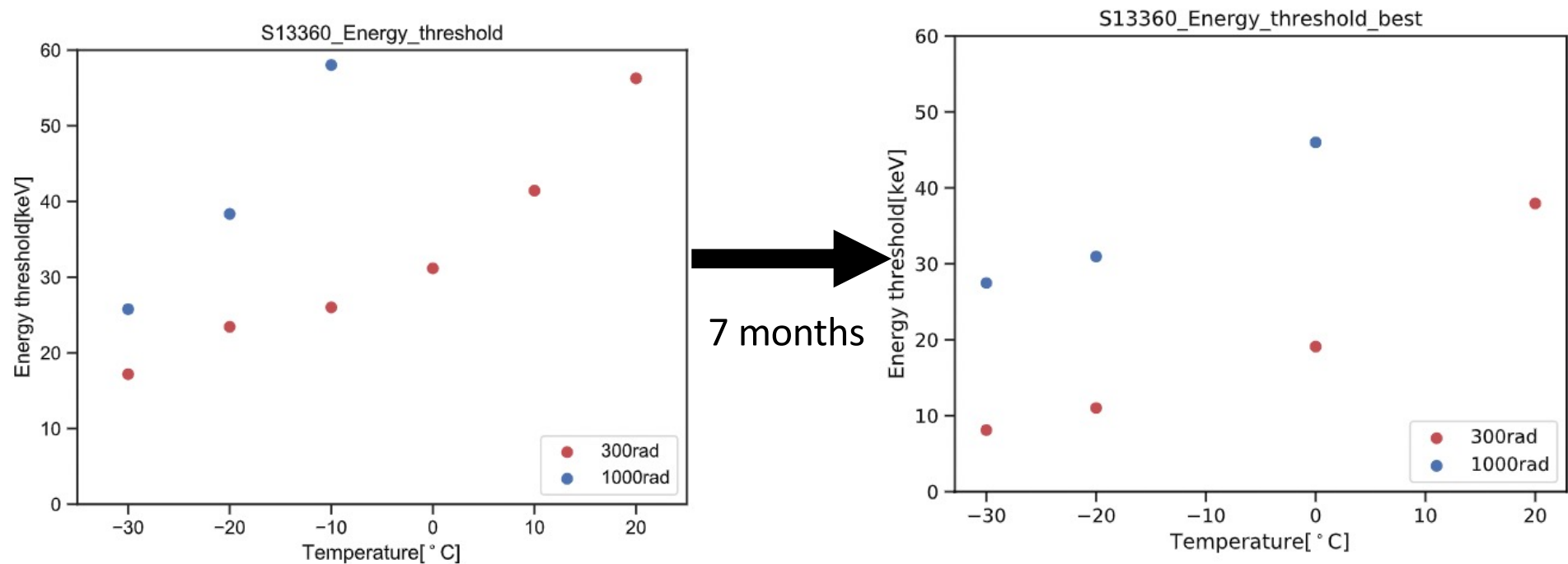
N. Hirade et al. 2021

Energy Threshold

To examine annealing, the energy threshold was set to the 4-sigma channel of noise and evaluated.

# After kept in room temperature

S13360-6050CS

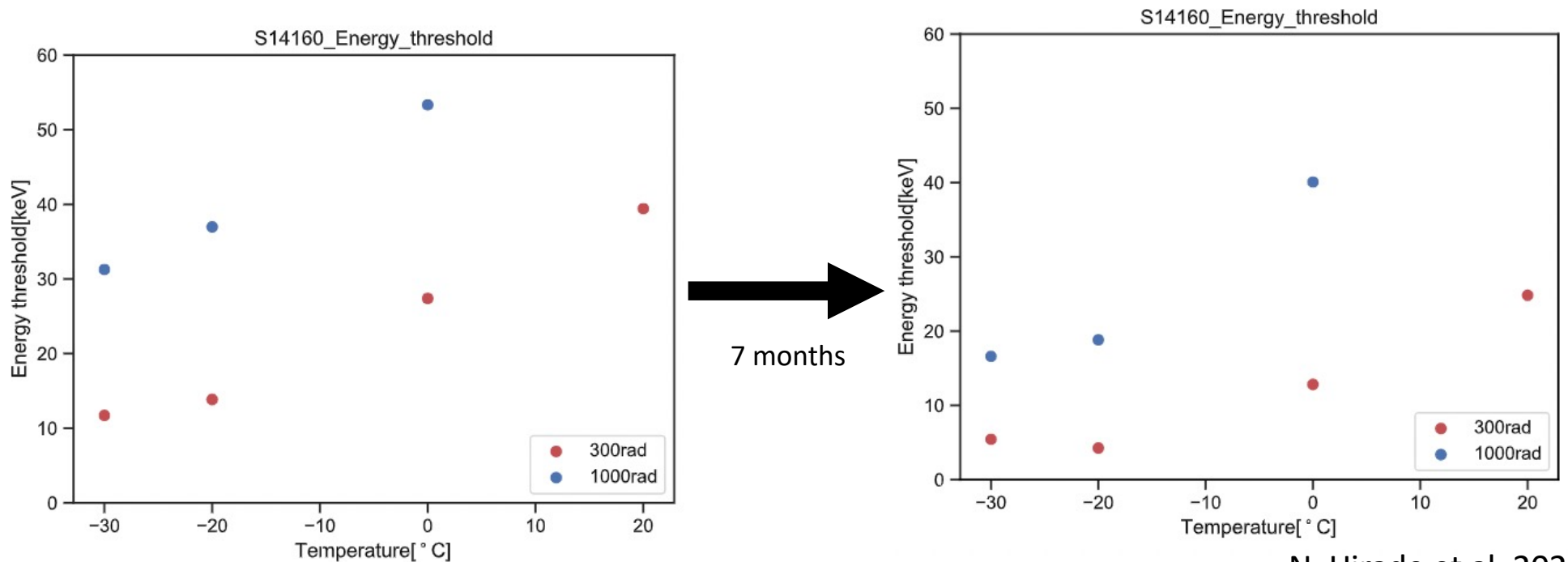


N. Hirade et al. 2021

In 7 months, the energy threshold decreased.  
MPPCs of S13360-6050CS are recovered in 7 months.

# After kept in room temperature

S14160-6050CS



N. Hirade et al. 2021

In 7 months, the energy threshold decreased for all data.  
MPPCs of S14160-6050CS are recovered in 7 months.

## After baked at 150 °C for 3 hours

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MPPCs	Irradiation date (2018)	Irradiation date (2019)	Irradiation date (2020)
S14160-3015PS			✓
S14160-3050HS			✓
S14160-6050CS		✓	
S14420-3050 MOD			✓
S14160-3050 MOD			✓
S13360-6050CS	✓		



Annealing after baked at 150 °C for 3 hours

# After baked at 150 °C for 3 hours

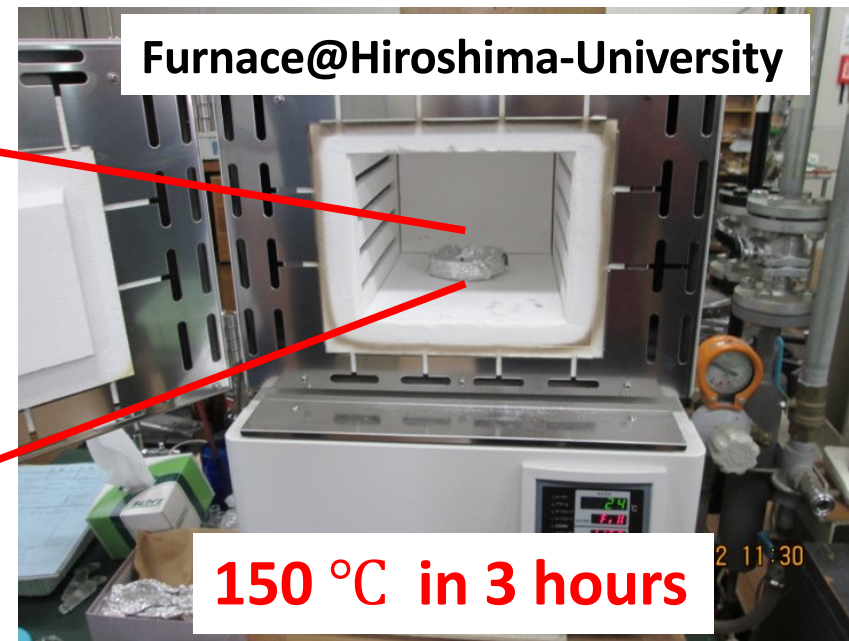
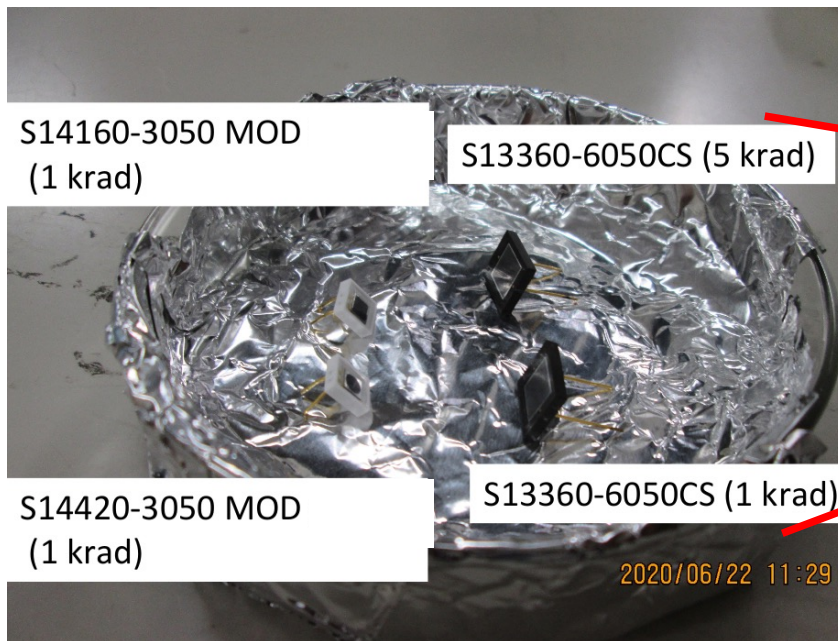
MPPCs: S13360-6050CS (1000 rad and 5000 rad)

→ irradiated in May 2018

S14420-3050 MOD (1000 rad)  
S14160-3050 MOD (1000 rad)

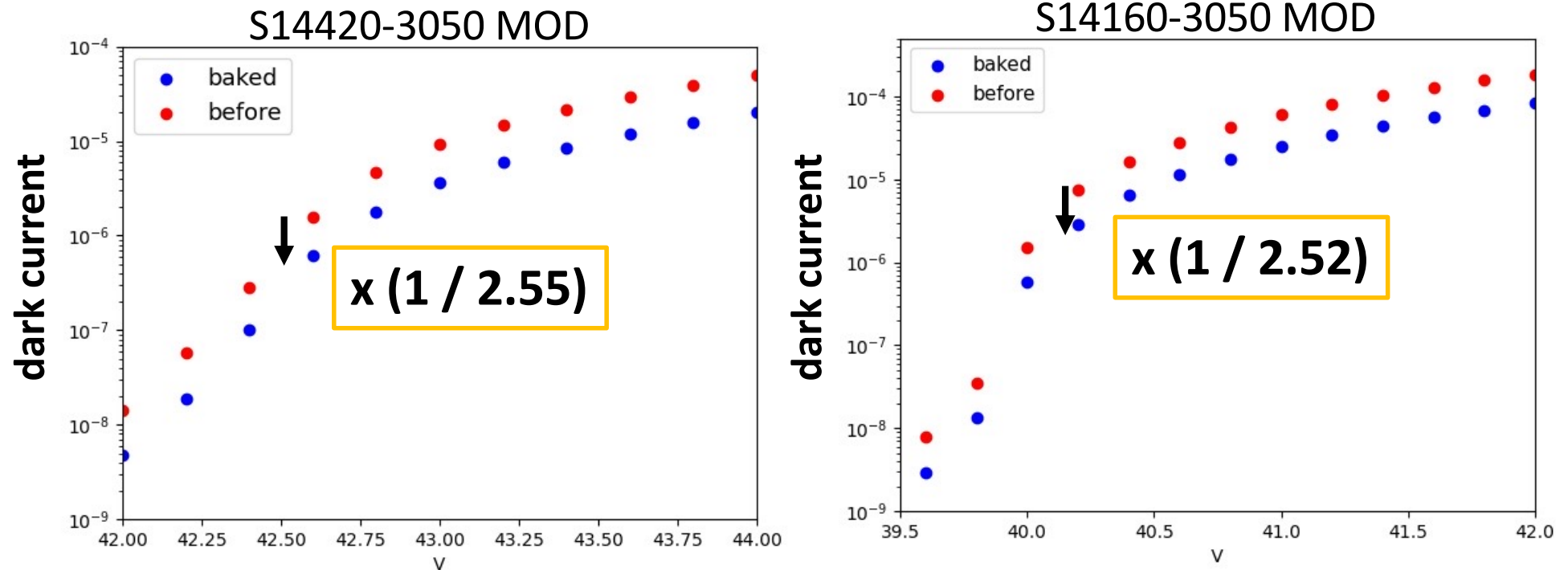
→ irradiated in April 2020

## Baking in Jun 2020



# After baked at 150 °C for 3 hours

S14420-3050 MOD and S14160-3050 MOD

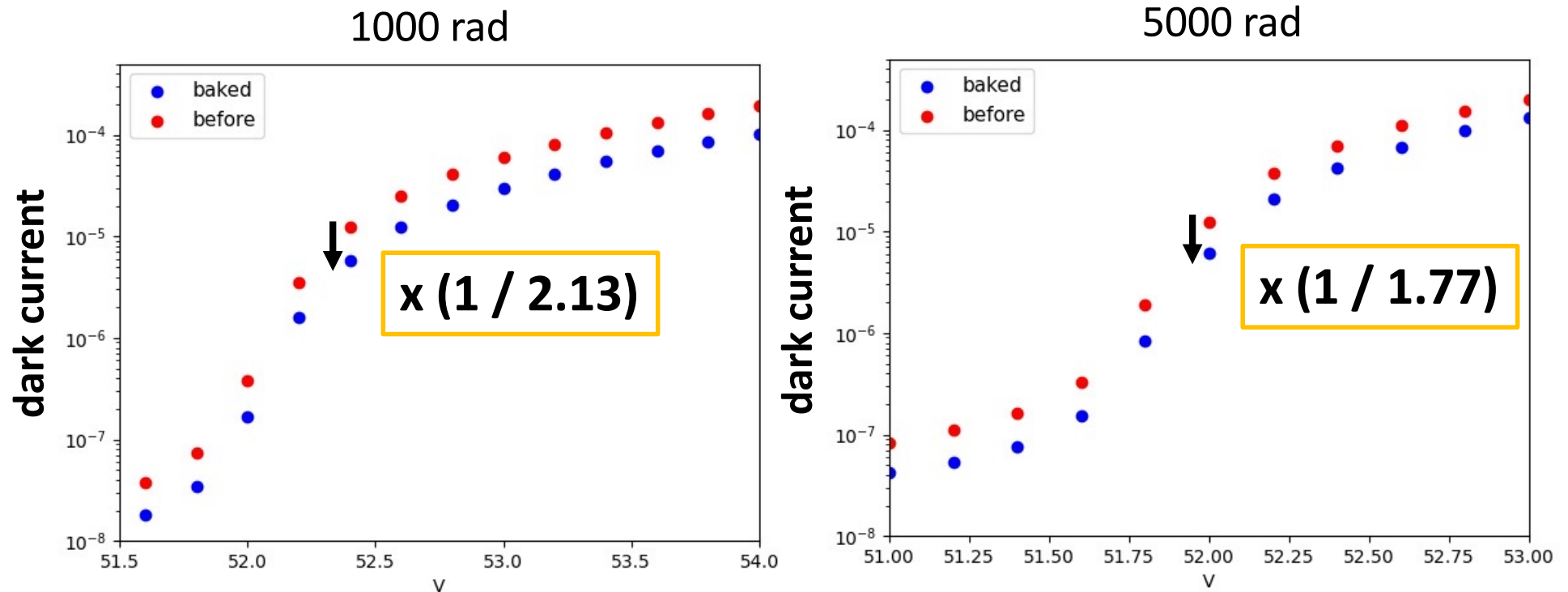


These dark currents are reduced approximately 50 %.

We think that S14420-3050 MOD and S14160-3050 MOD are annealed.

# After baked at 150 °C for 3 hours

S13360-6050CS (1000 rad and 5000 rad)



As in S14s, these dark currents are reduced approximately 50 %.  
We think that S13360-6050 (1000 rad and 5000 rad) are annealed.

## After baked at 150 °C for 3 hours

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### Short summary

MPPCs	Decrease of dark current	
S14420-3050 MOD	1/2.55 ~ 0.39	→ 2 months after irradiated
S14160-3050 MOD	1/2.52 ~ 0.40	
S13360-6050CS (1000 rad)	1/2.13 ~ 0.47	→ 25 months after irradiated
S13360-6050CS (5000 rad)	1/1.77 ~ 0.56	

The dark current was reduced by approximately 50% after baking at 150 °C for 3 hours.

We think the decrease of S13360-6050CSs is lower because they've already reduced the dark current to 1/3 during 25 months before they were baked.

Comparing MPPCs irradiated 1000 rad and 5000 rad, the larger irradiation dose possibly results in a lower rate of decrease.



# Summary

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We reported 2 results of annealing.

One was kept at room temperature for 7 months and the other was baked at 150 °C for 3 hours.

- keeping at room temperature (20 °C) caused annealing, and approximately 50% recovery was observed after 7 months.  
We can confirm the annealing at one month after irradiation.
- Baking resulted in approximately 50% reduction in dark current for all MPPCs.  
It is also possible that the larger the irradiation dose, the smaller the reduction due to baking.
- In the future, irradiation experiments will be conducted using the latest MPPC to continue performance verification.

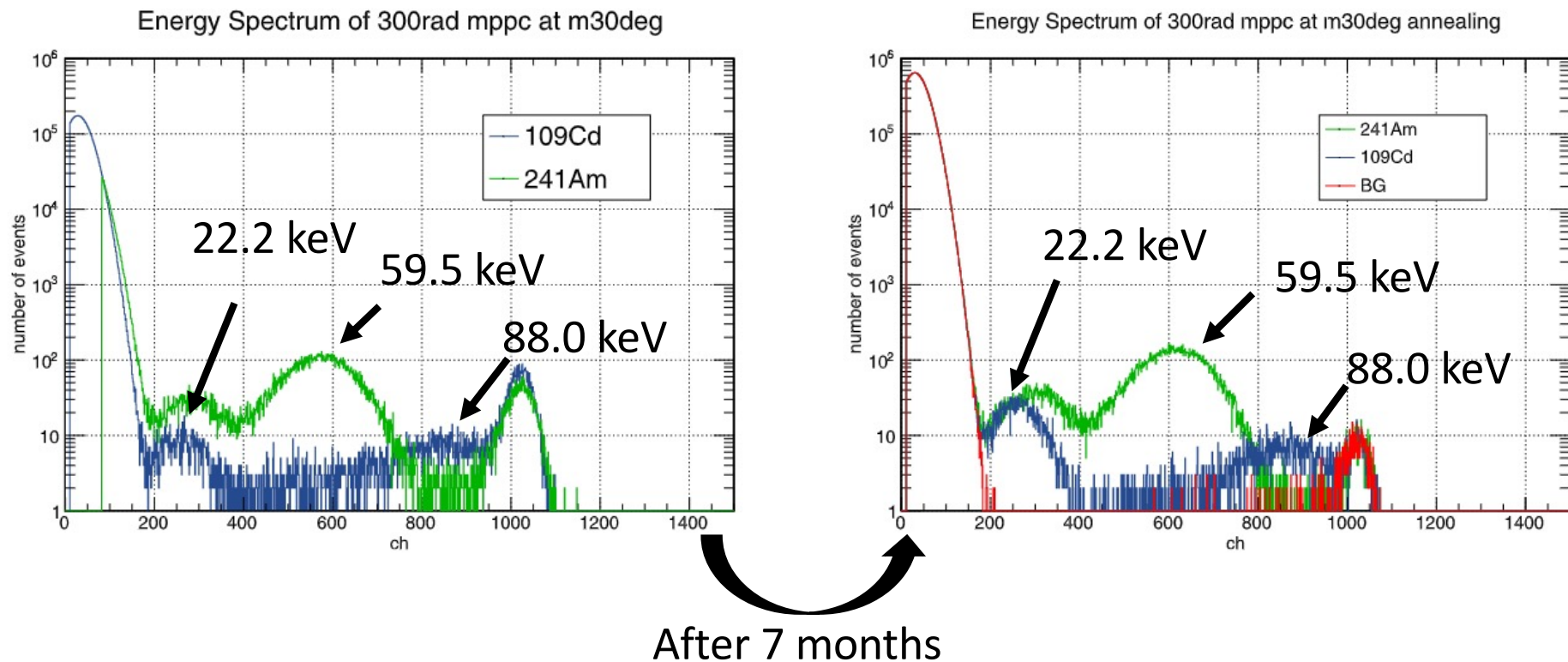
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# After kept in room temperature

S14160-6050CS

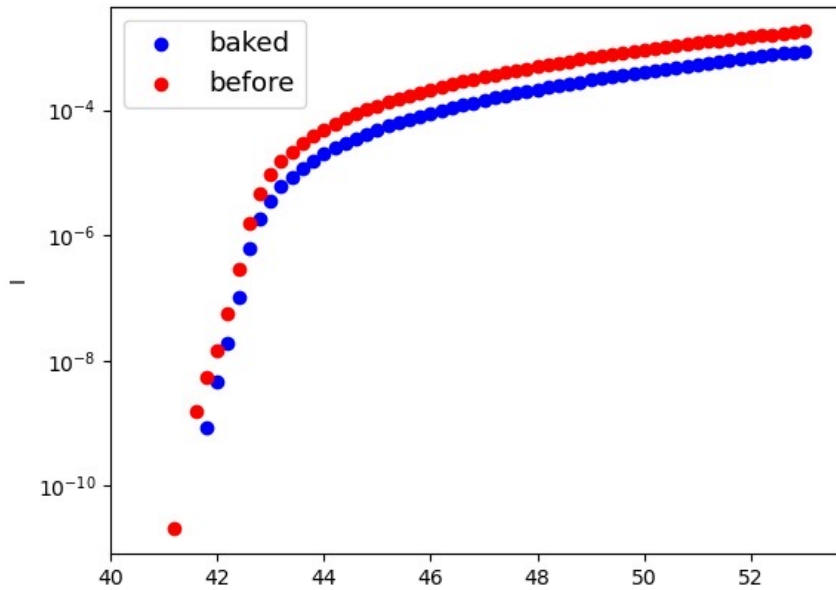
We used a MPPC irradiated with 300 rad at -30 °C.



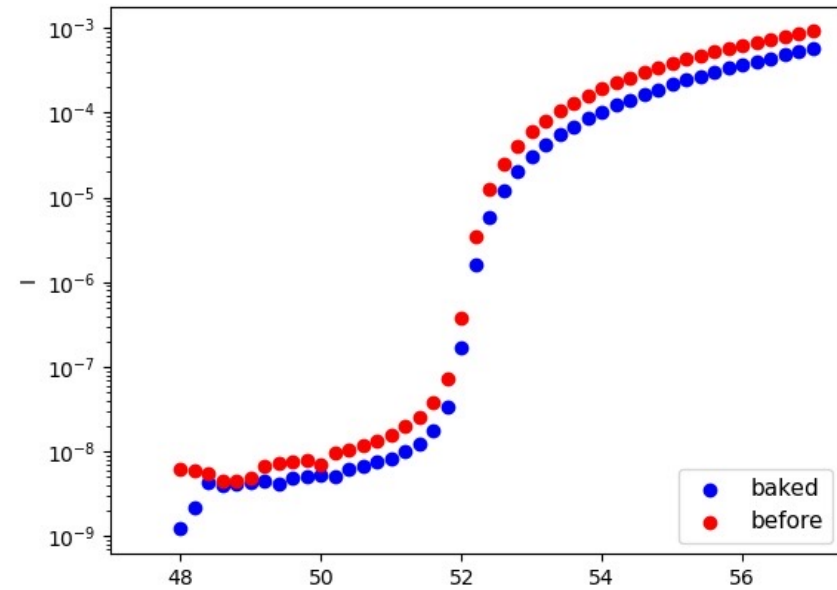
The  $^{109}\text{Cd}$  was measured one month later after irradiation.  
 The noise count is lower in the  $^{109}\text{Cd}$  than in the  $^{241}\text{Am}$ .  
 As in S13360-6050CS, we can think that they are annealed.

# After baked at 150 °C for 3 hours

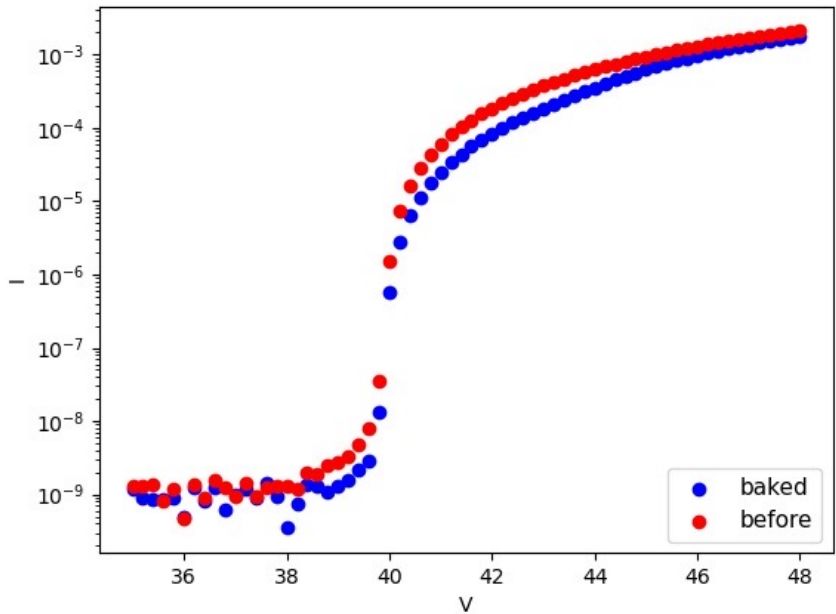
14420



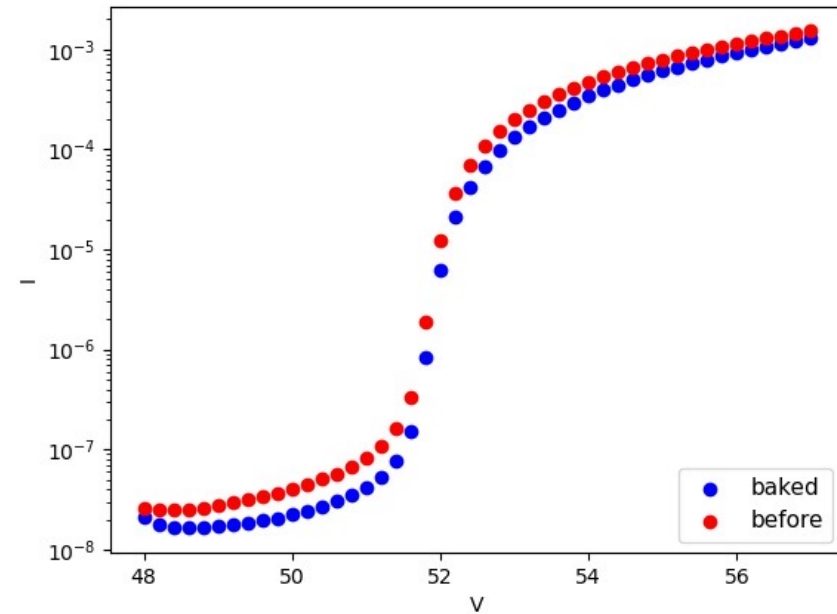
S13 1 krad



14460



S13 5 krad



# After kept in room temperature

**Table 1**

Properties of S13360-6050CS and S14160-6050HS.

Model	S13360-6050CS	S14160-6050HS
Type	Lead	Surface mount
Gain ( $10^6$ )	1.7	2.5
Operation $V_{op}$ (V)	54.4	41.0
PDE (%)	49	50
Dark current ( $\mu\text{A}$ )	0.4	1.6

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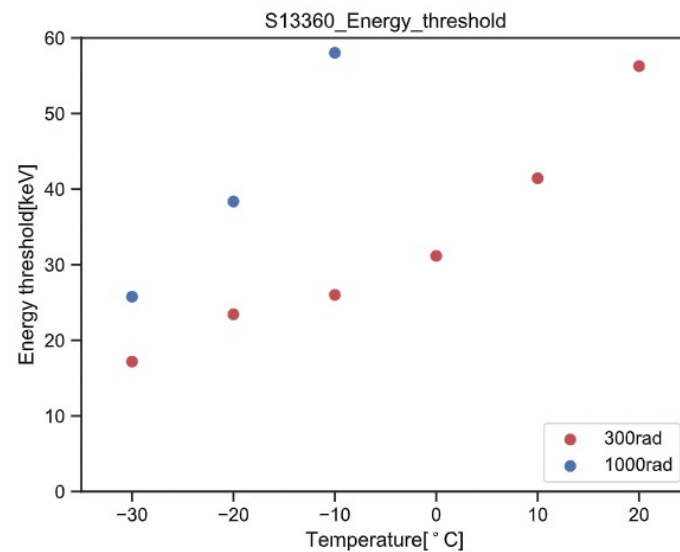
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MPPCの周りが黒いのと白いのによるちがい  
→たしか平出論文に書いてあった。

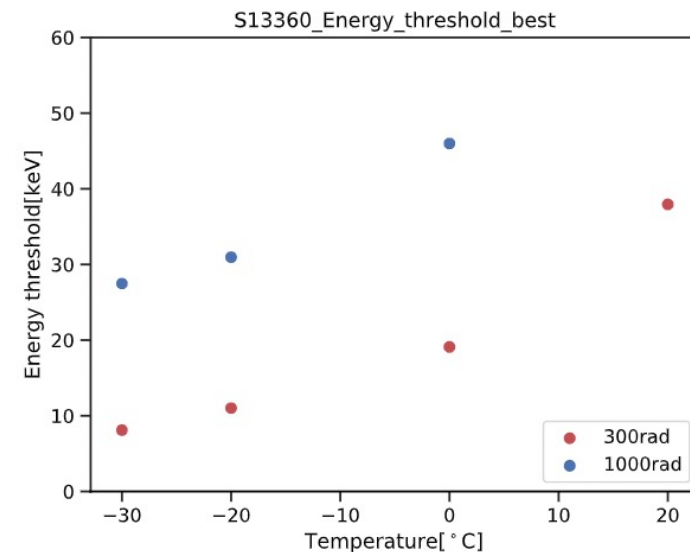
# After kept in room temperature

- We made calibration line using peaks of  $^{241}\text{Am}$  (59.5 keV) and  $^{109}\text{Cd}$  (88.0 keV).
- The energy threshold corresponds to the 4-sigma noise channel when fitting with Gaussian.

## S13360-6050CS



7 months



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After 7 months the energy threshold is better than previous one.  
MPPCs of S13360-6050CS are recovered in 7 months.

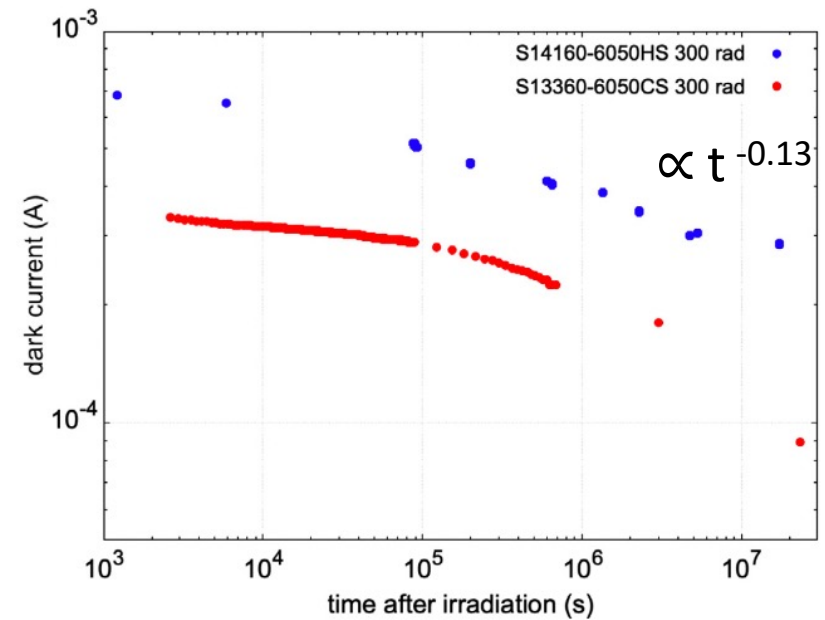
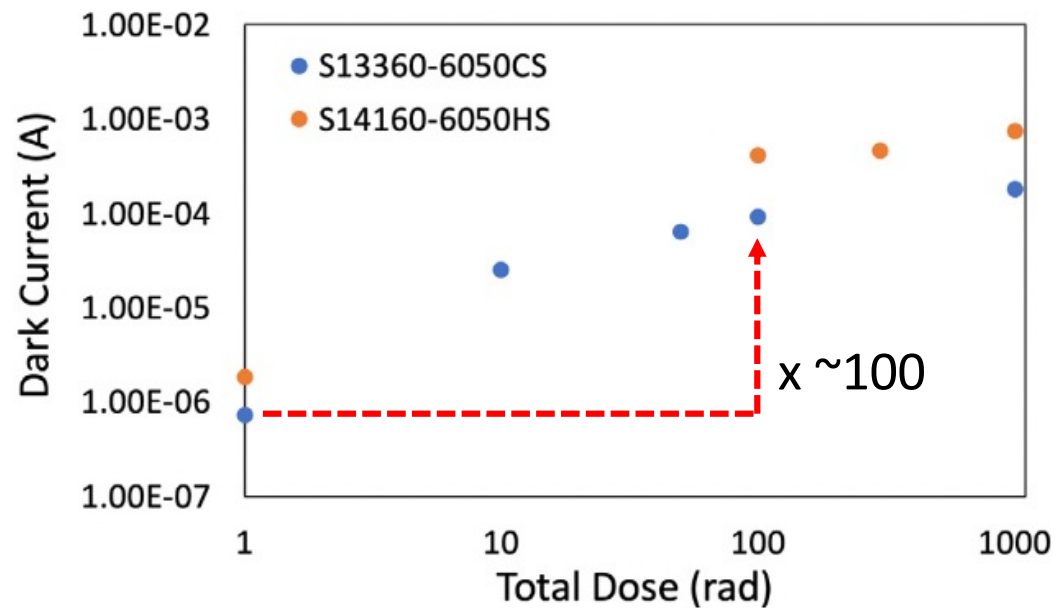
# After kept in room temperature

MPPCs: S13360-6050CS (300 rad, 1000 rad and 5000 rad)

10, 50, 100, 1000 rad

S14160-6050CS (300 rad, 1000 rad and 5000 rad)

100, 300, 1000 rad



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