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Radiation damage of MPPC by gamma-ray irradiation with ^{60}Co

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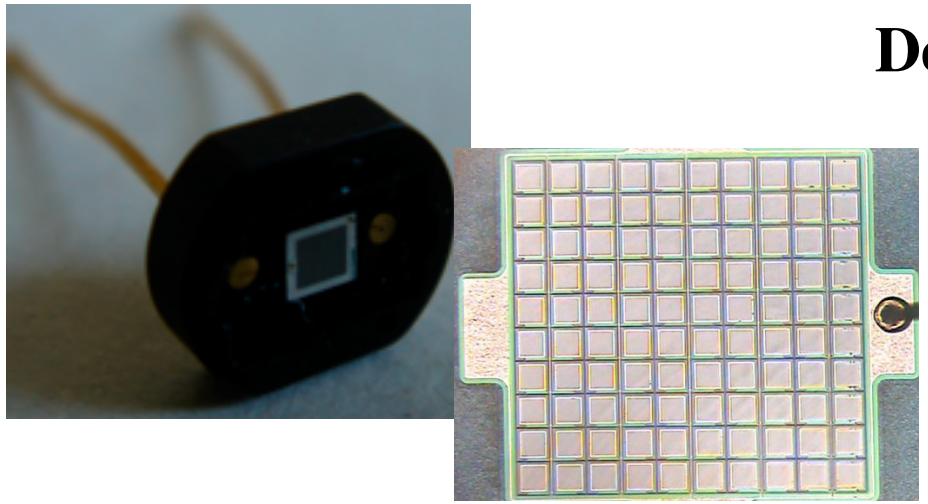
- Motivation
- Test method
- Leakage current measurement
- Radiation effect measurement
  (Gain, Noise rate, Crosstalk)
- Evaluation of radiation damage
- Summary

Motivation



Developed by Hamamatsu Photonics

Small size
High gain (10^5~10^6)
Not susceptible to magnetic field
Operation at low bias voltage
Low cost

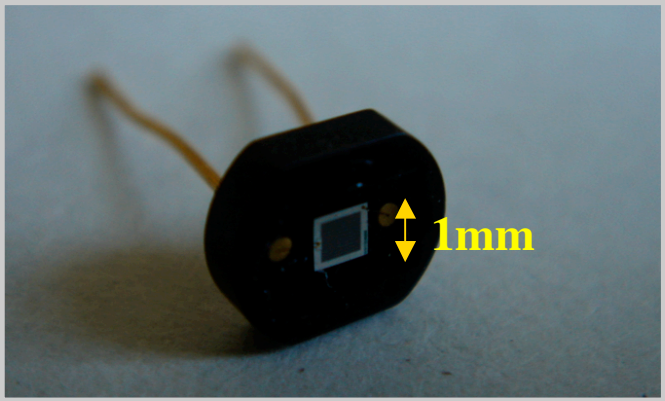
MPPC will be used in high energy physics
→ Radiation damage is problem for considering applications

MPPC is new developed device, and radiation resistance is unknown
→ We studied radiation damage using ^{60}Co gamma-ray

See T. Tanaka's poster about heavy ion irradiation
and T. Matsumura's talk about proton & neutron irradiation

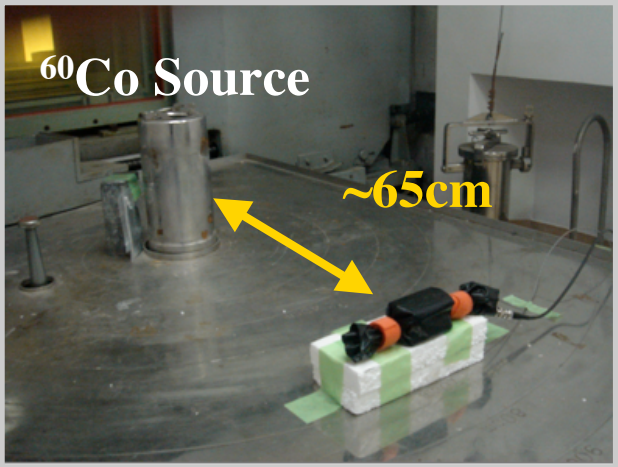
Test method (1)

Test Sample



Type No : T2K-11-100C (100 pixels)
Vop : 70.7 V (ΔV=1.2 V)
Dark Noise : 334 kHz (0.5 p.e.thr.)
38 kHz (1.5 p.e.thr.)
[Condition : 25℃]

^{60}Co gamma-ray irradiation facility in Tokyo Tech



Radiation Source : ~15TBq ^{60}Co Source
γ-ray energy : 1.173 MeV, 1.332 MeV
Dose rate : distance dependence
(few % error)

Test method (2)

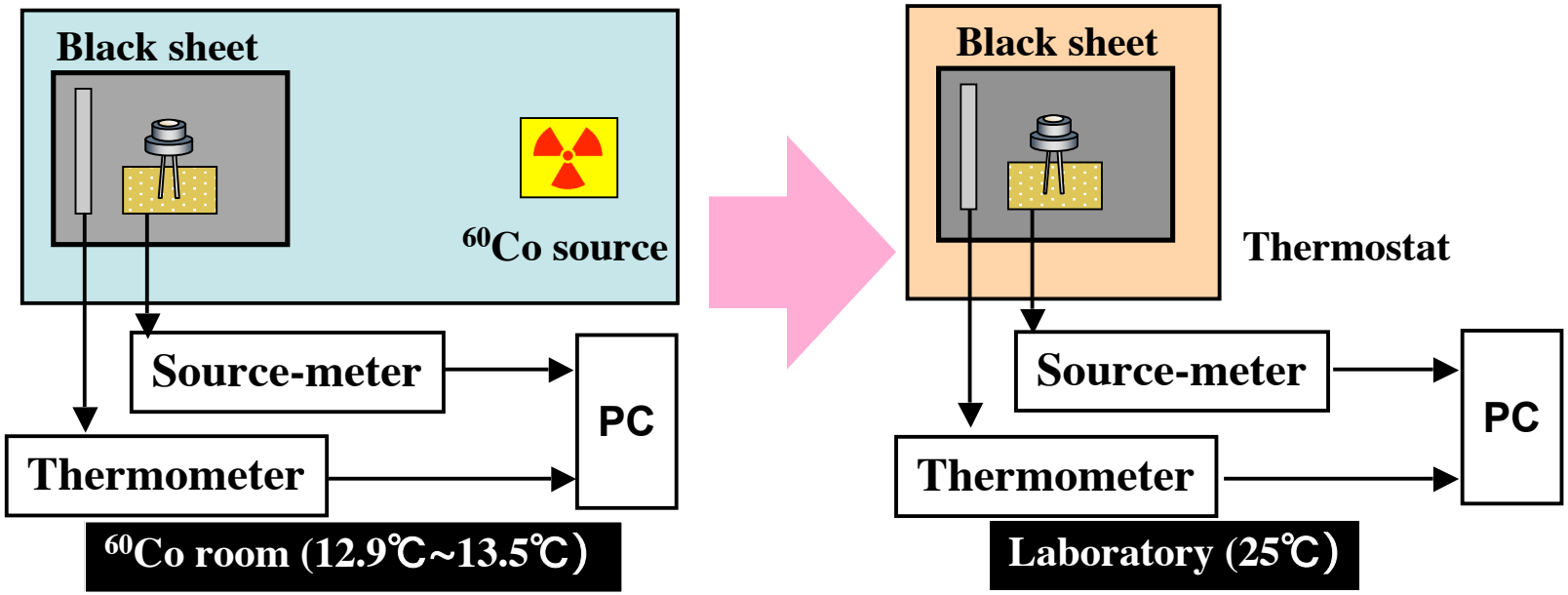
Test flow	Measurement	Condition
40Gy Irradiation @^{60}Co room	Leakage Current (4h)	12.9℃~13.5℃ ΔV=1.2 V
Radiation effect measurement @Lab	Leakage Current (1h)	25℃ ΔV=1.2 V
	Gain	
	Noise rate	25℃
	Crosstalk	

Repeated 40 Gy irradiation (10 Gy/h×4h) 6 times
Total 240 Gy irradiation accumulated

Leakage current measurement

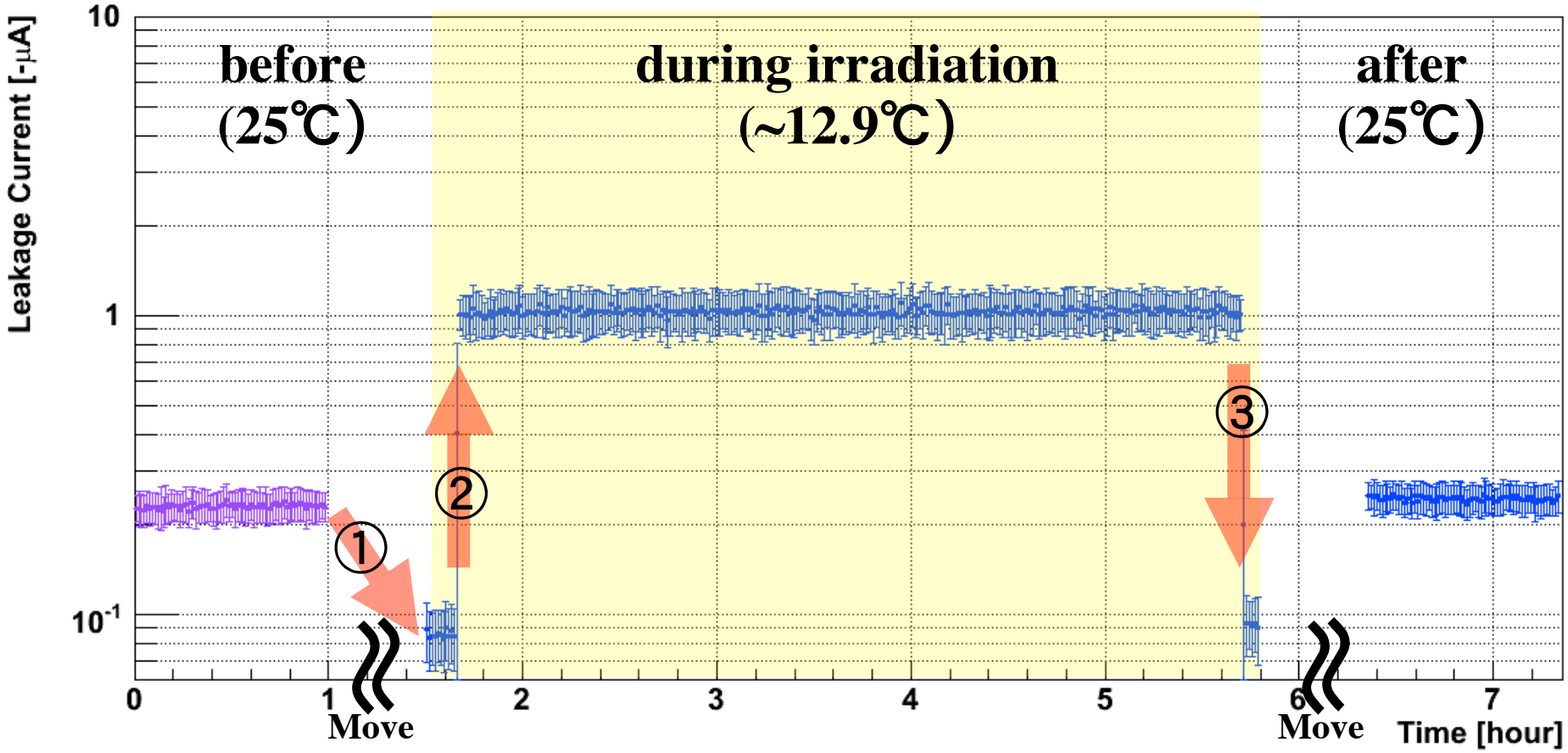
- Method of measurement
- Result of leakage current
  - during irradiation
  - after each irradiations
- High dark noise
- Infrared emission

Method of leakage current measurement



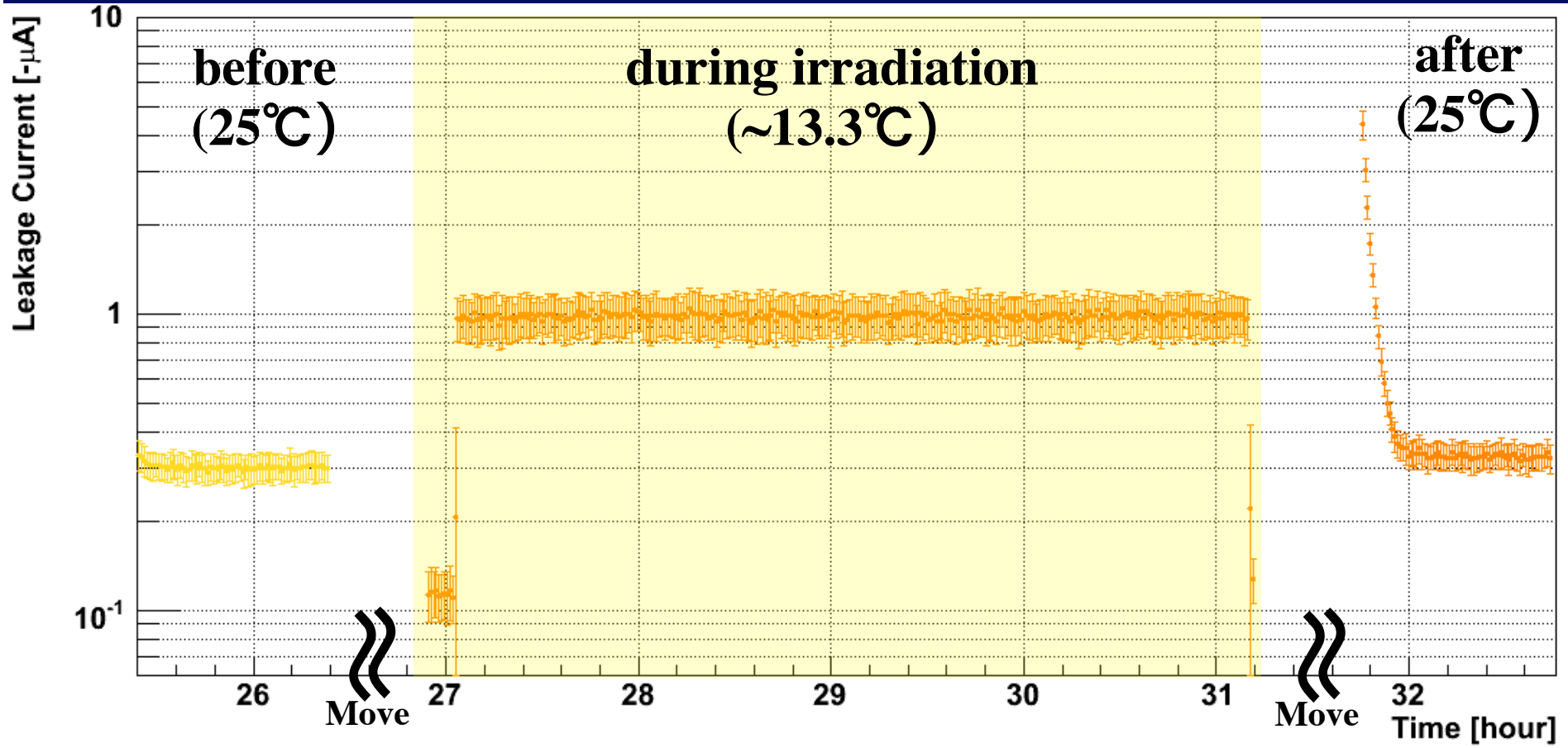
- Supply voltage and measure leakage current with Source-meter
- Irradiation increases leakage current
  → Radiation damage indicator

0 Gy to 40 Gy irradiation



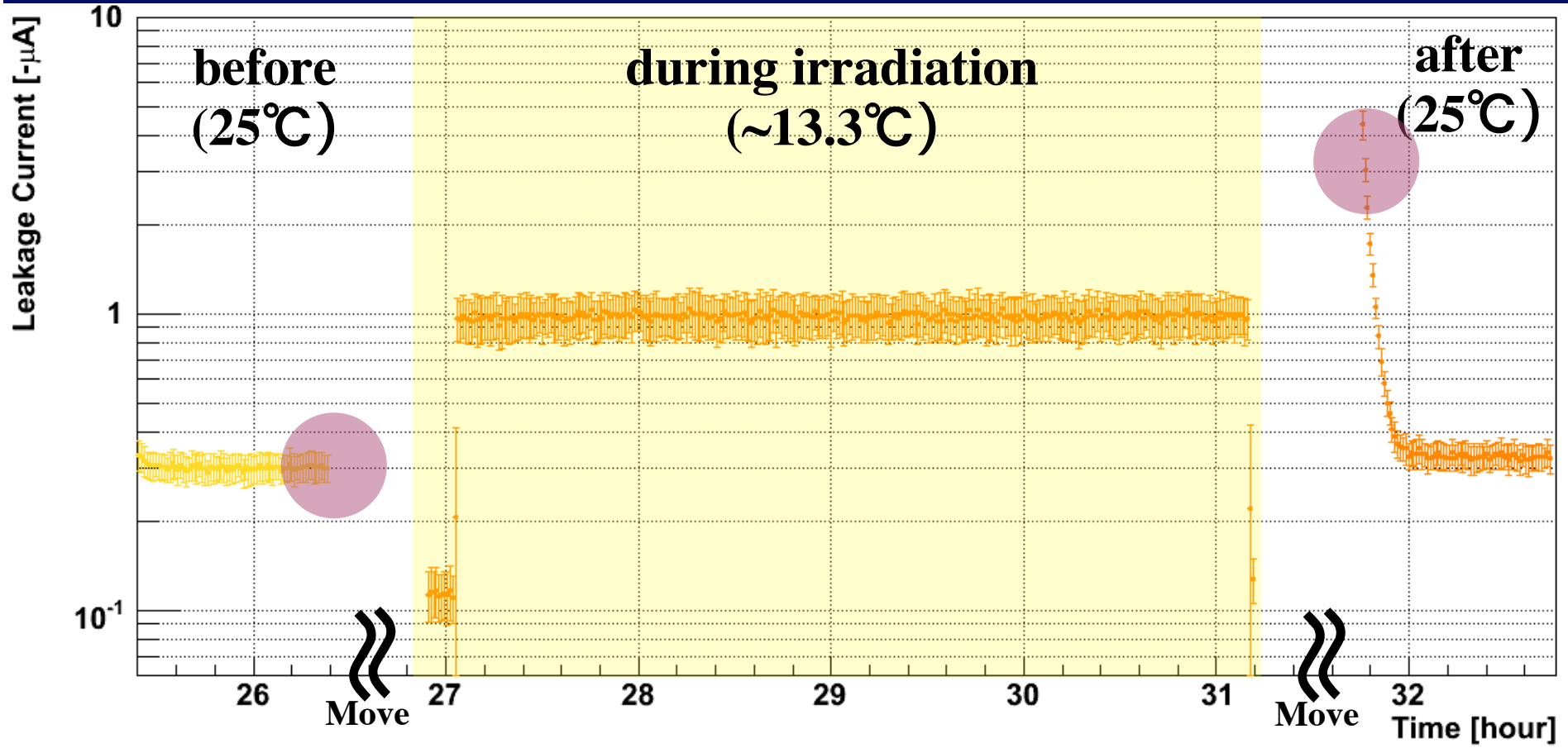
- ① Difference of temperature cause this change
- ② Irradiation starts
- ③ Irradiation ends

160 Gy to 200 Gy irradiation



- Leakage current change so much, to see before and just after
- After irradiation, leakage current decreased during ~10 min after voltage supplied → Annealing effect

160 Gy to 200 Gy irradiation



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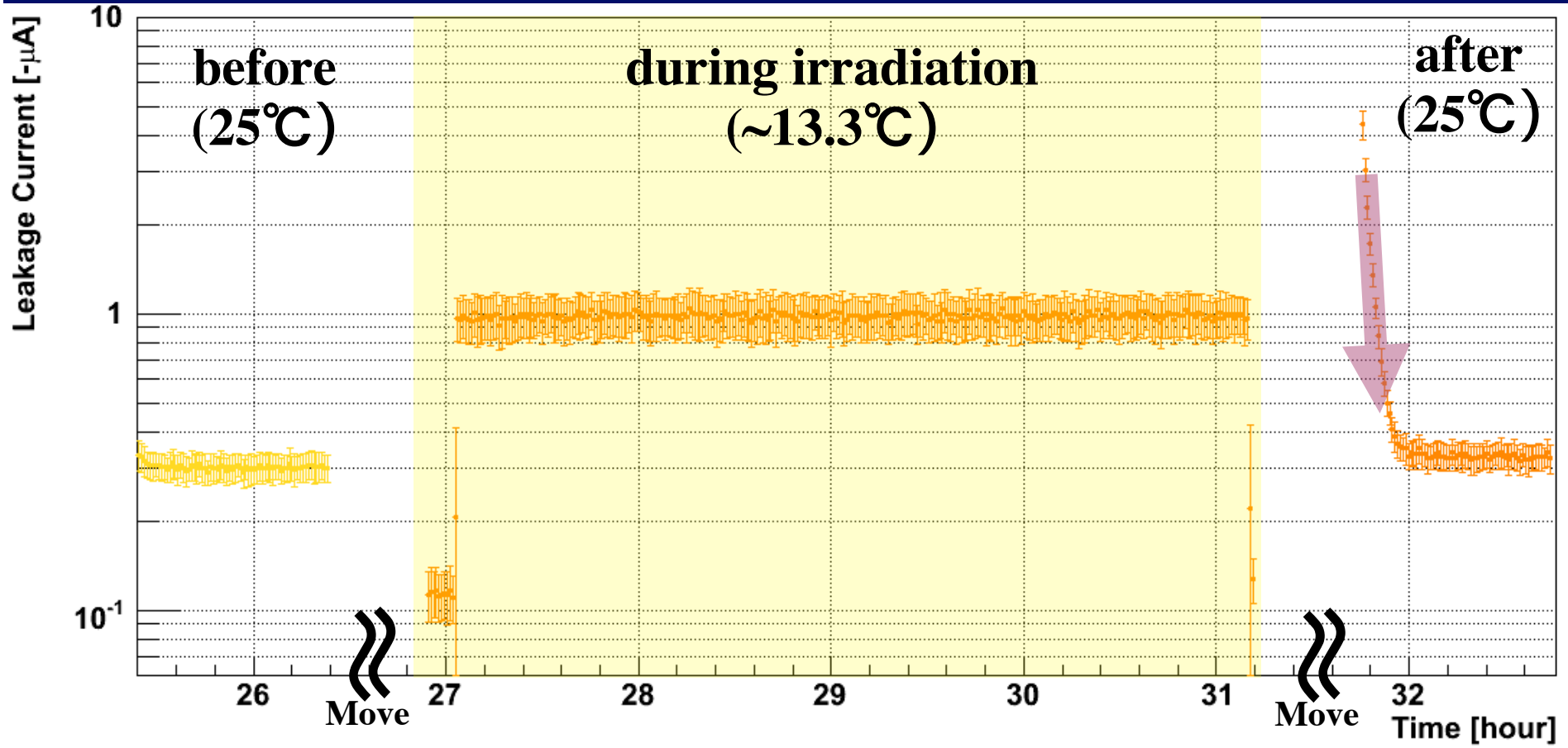

- Leakage current change so much, to see before and just after
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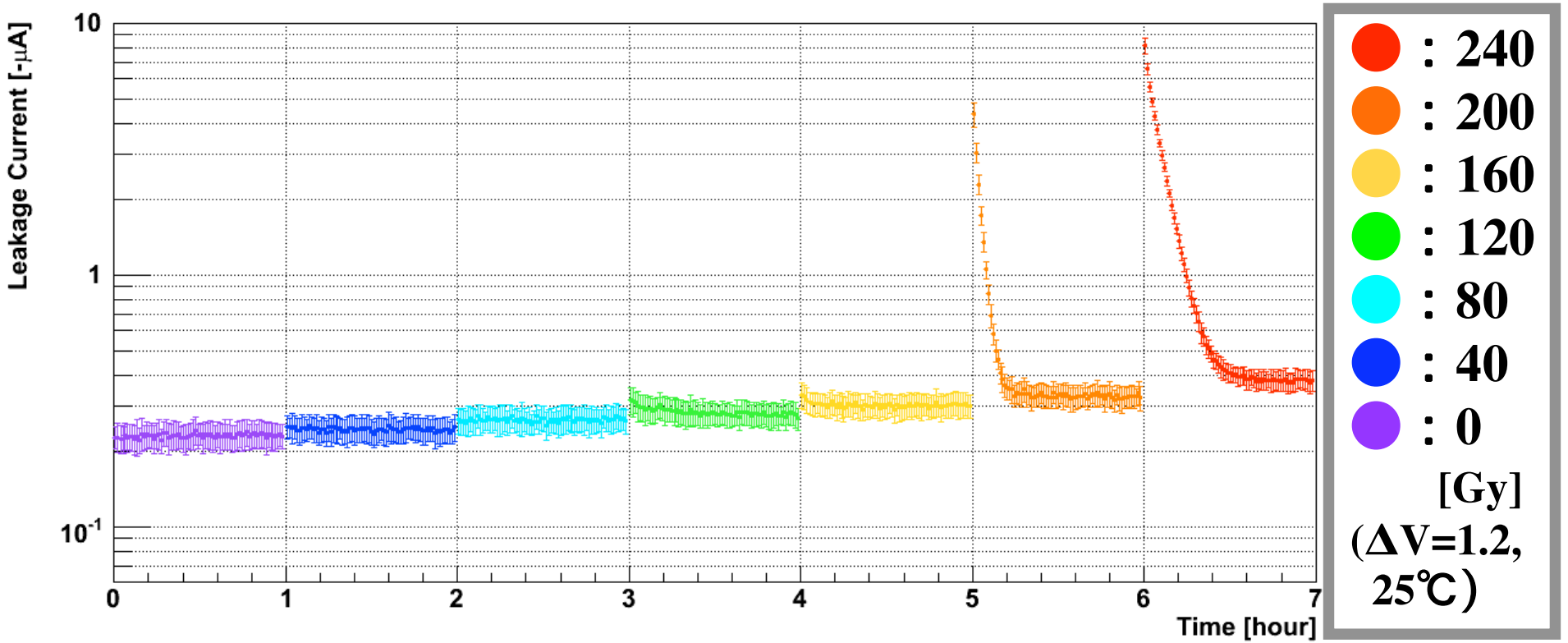
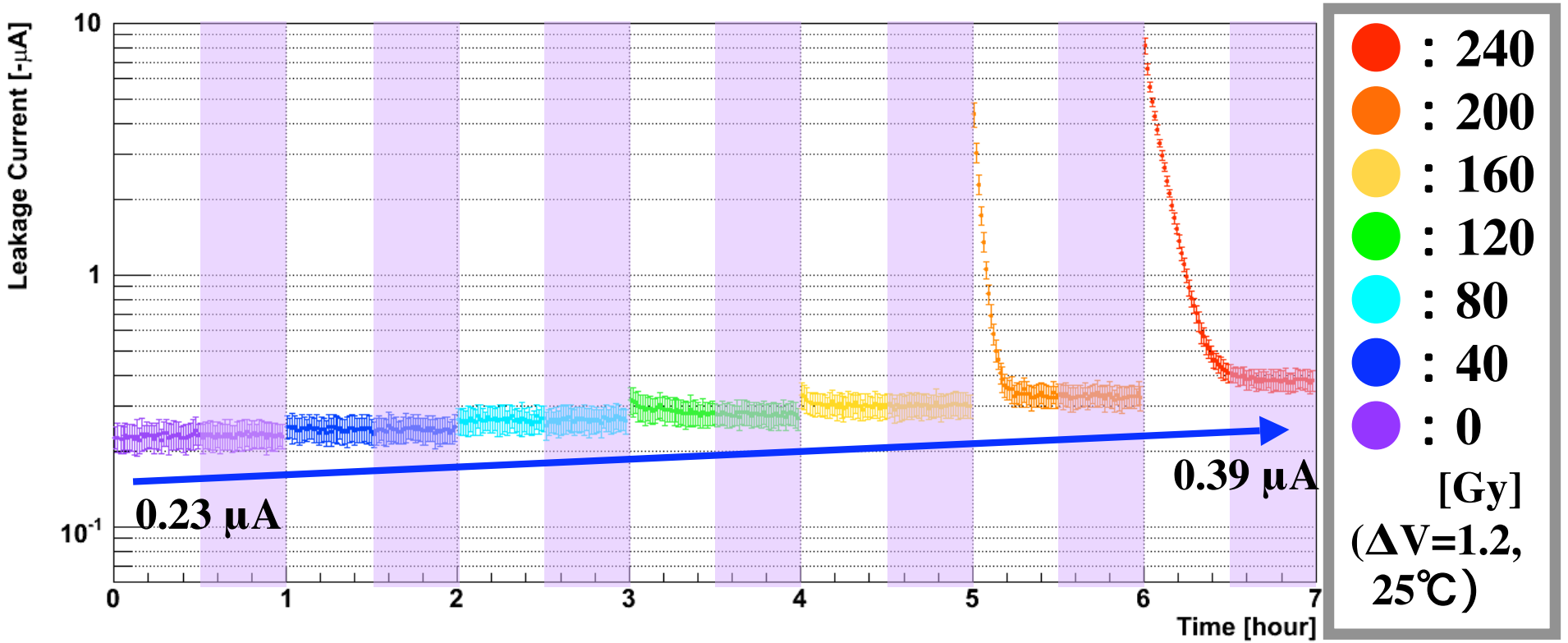
Leakage current after each irradiation



- Leakage current at V_{op} increased ~1.7 times by these irradiations comparing the second half of each data
- Annealing effect were observed from 120Gy irradiation
- Leakage current changed so much just after 200Gy and 240Gy

Leakage current after each irradiation



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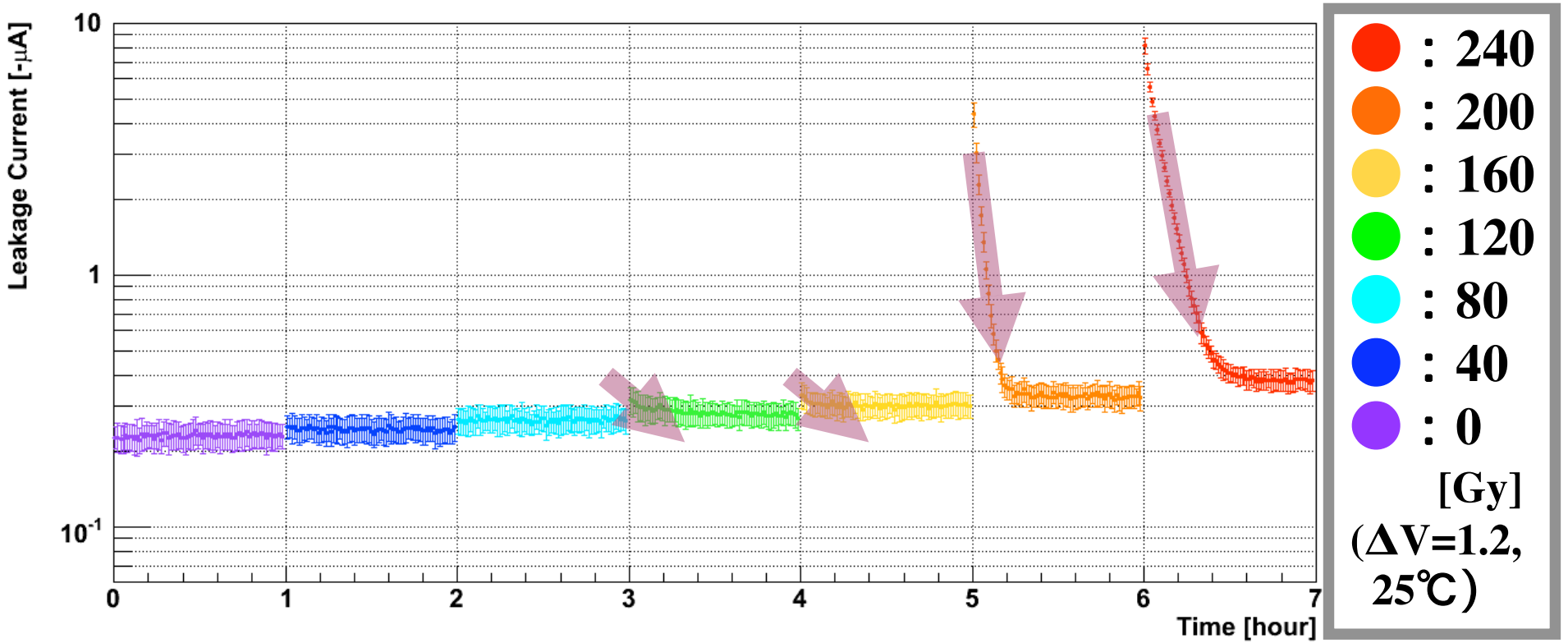

- Leakage current at V_{op} increased ~1.7 times by these irradiations comparing the second half of each data (0.23 μA → 0.39 μA)
- Annealing effect were observed from 120Gy irradiation
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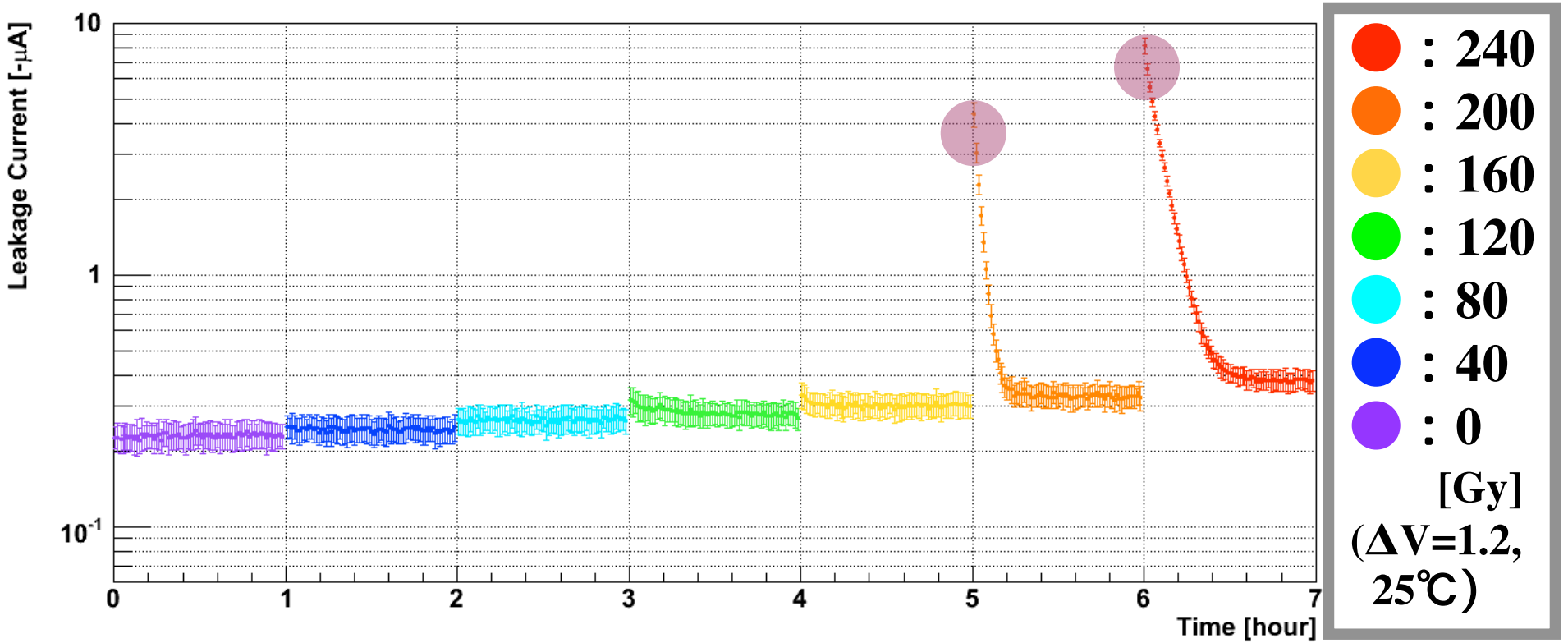
Leakage current after each irradiation



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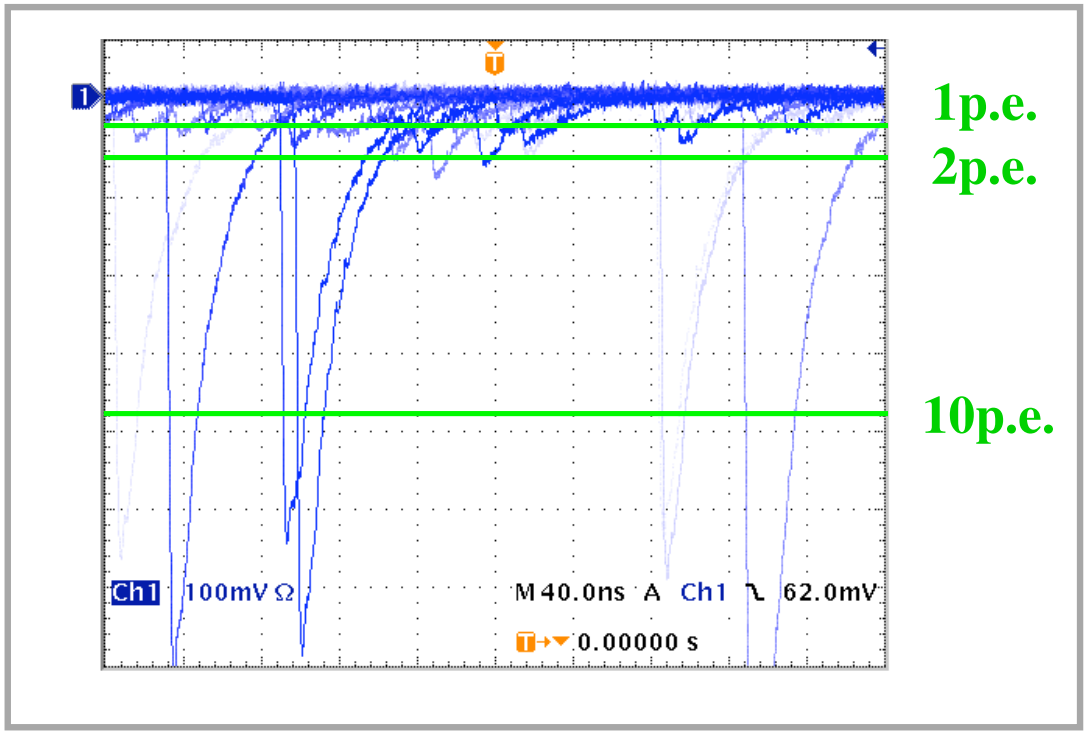
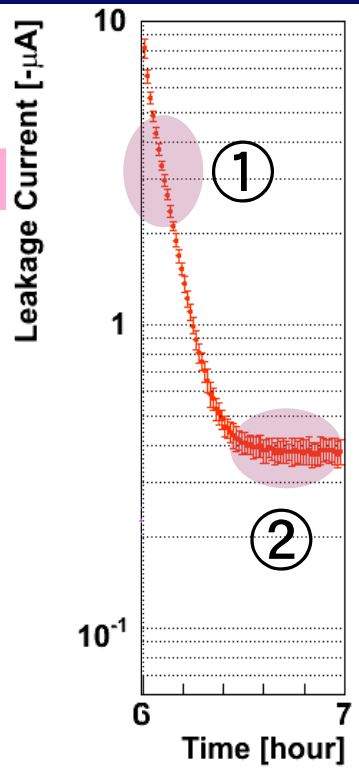
High dark noise



Waveform (AMP×50)

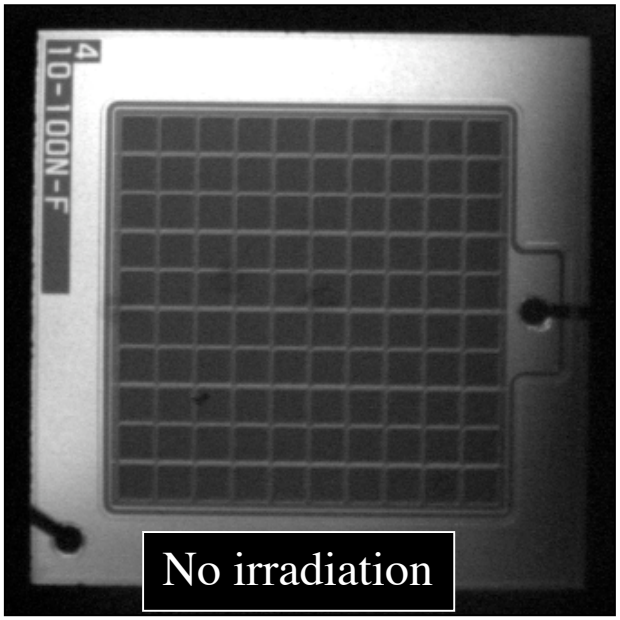


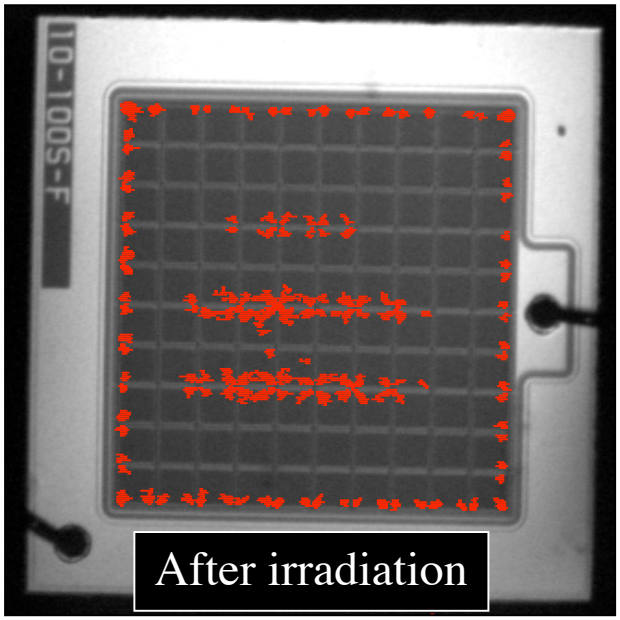
After 240 Gy irradiation

- ① High dark noises were observed during high leakage current
- ② The high dark noises disappeared, as leak current get settled
- Turn off voltage, wait for a while, and turn on, this phenomena appeared again

Infrared emission

- We took a picture by infrared camera, supplying bias voltage in order to look at where the high dark noise generated
- A large current flows in the red area





- We find the localized spot where the high dark noise generated
  - Outer edge of device and along the bias lines (to see full device)
  - Edge of a pixel (to see 1 pixel)

(＊)Bias lines exist alternately

Damage effect measurement

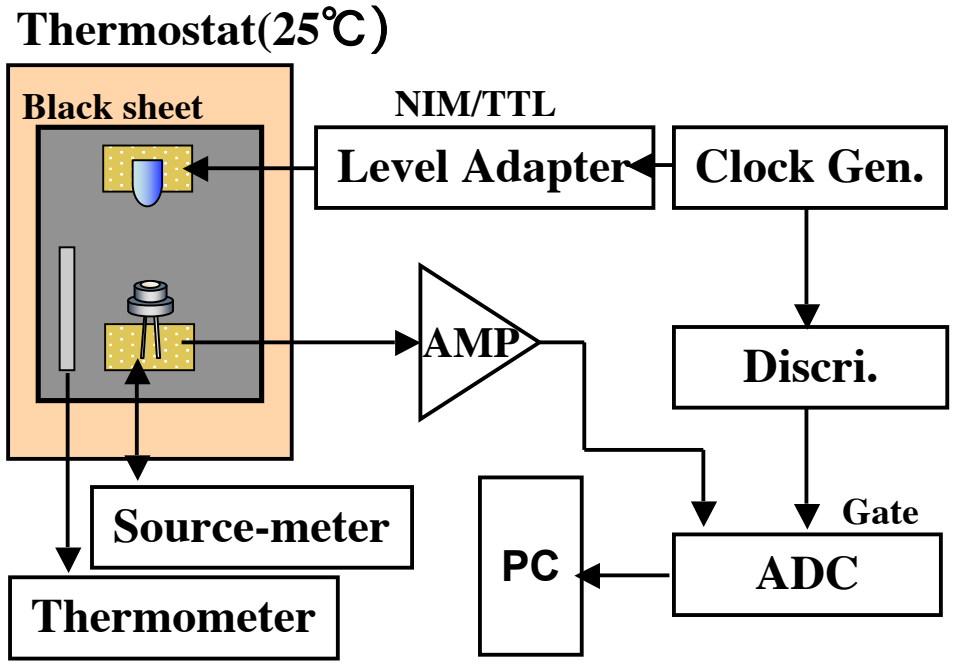
- **Measurement items**
  - **Gain**
  - **Noise rate**
  - **Crosstalk**

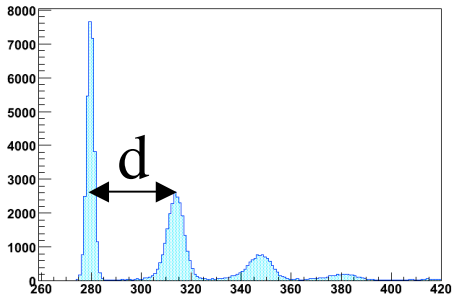
Method of Gain measurement

- Shed LED light pulses to MPPC and measure ADC distribution
- d (= 1p.e peak - pedestal peak) and caluculate gain with following formula

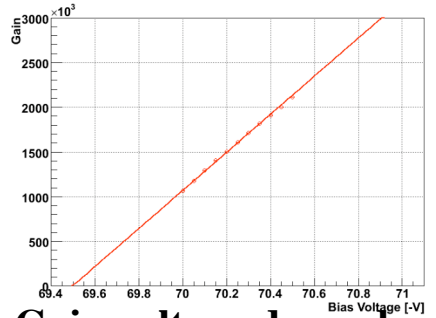
$$\text{Gain} = Q_{\text{pixel}} / e = \frac{d \times \text{ADC resolution}}{\text{AMP gain} \times e}$$

- Change voltage, calculate gain in the same way



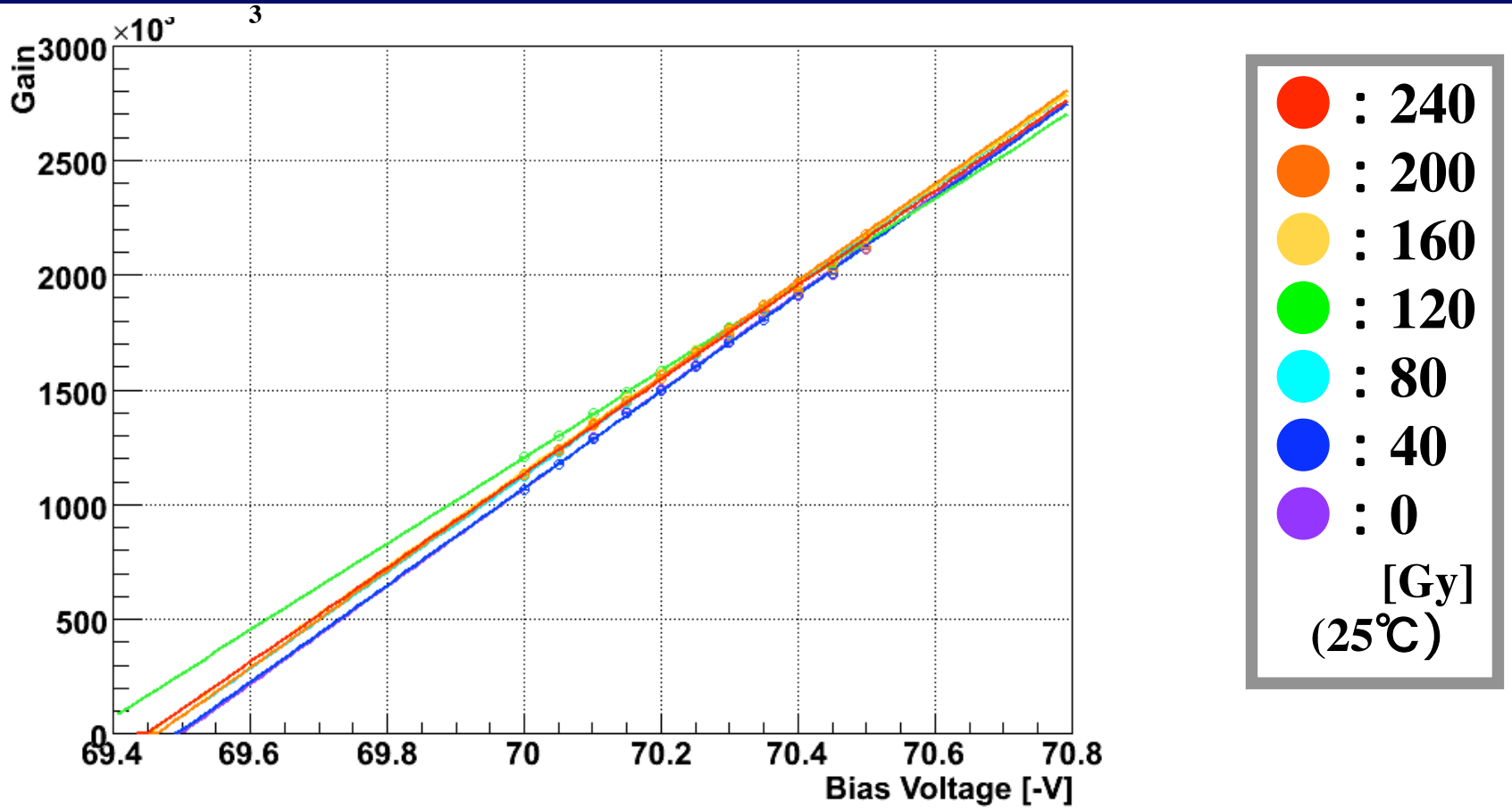


ADC distribution



Gain voltage dependence

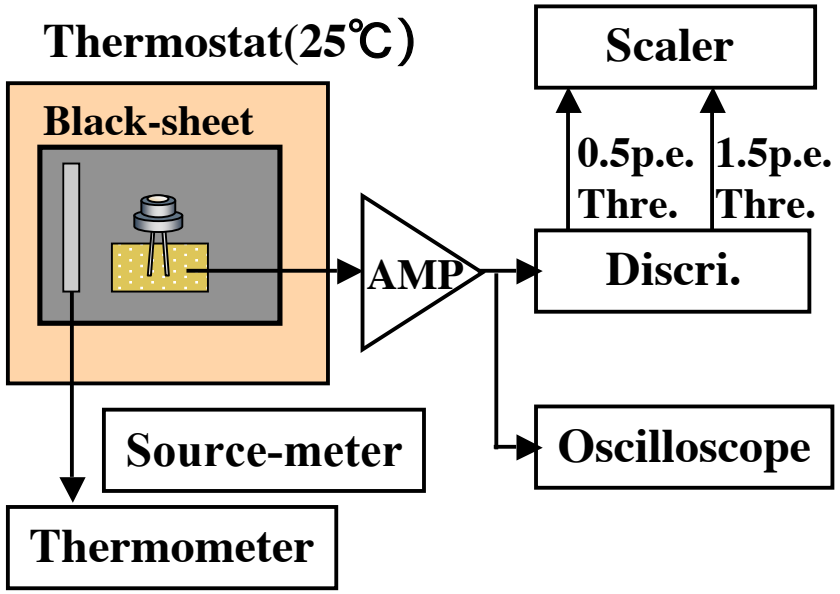
Gain vs Bias voltage



- **No significant change was observed**
  Variation of the gain within the systematical effect by temperature

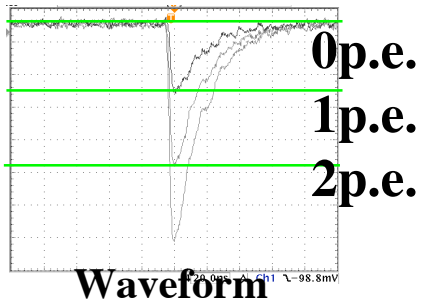
Method of Noise rate, Crosstalk

- Decide 0.5, 1.5 p.e. threshold by oscilloscope
- Measure noise rate by scalar
- Calculate crosstalk



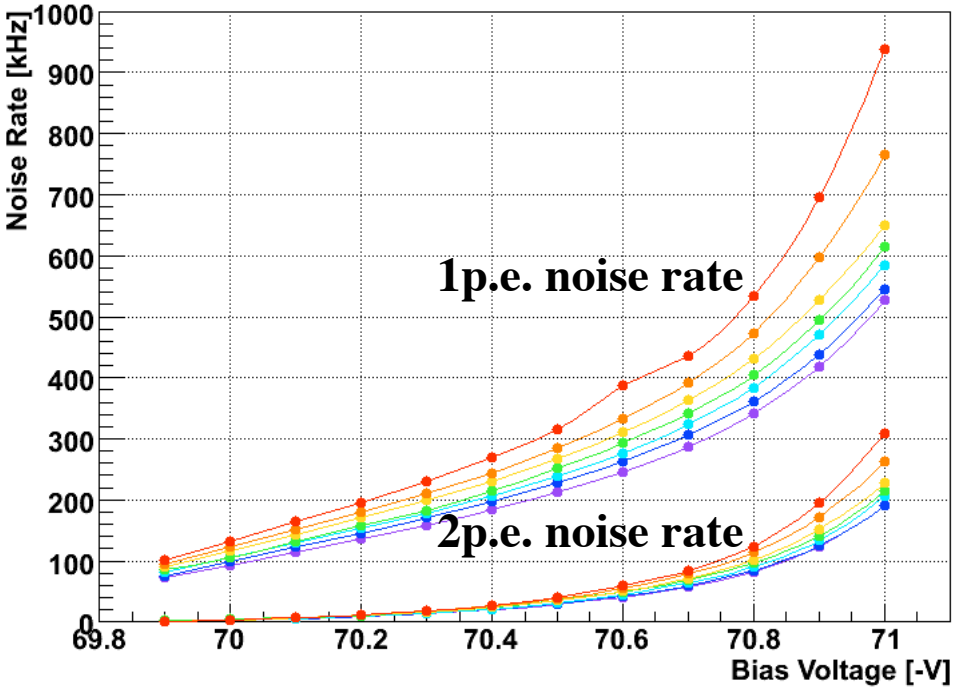
Rate of 0.5p.e. threshold ⇒ 1p.e. noise rate
Rate of 1.5p.e. threshold ⇒ 2p.e. noise rate

$$\frac{\text{2p.e. noise rate}}{\text{1p.e. noise rate}} \Rightarrow \text{Crosstalk}$$

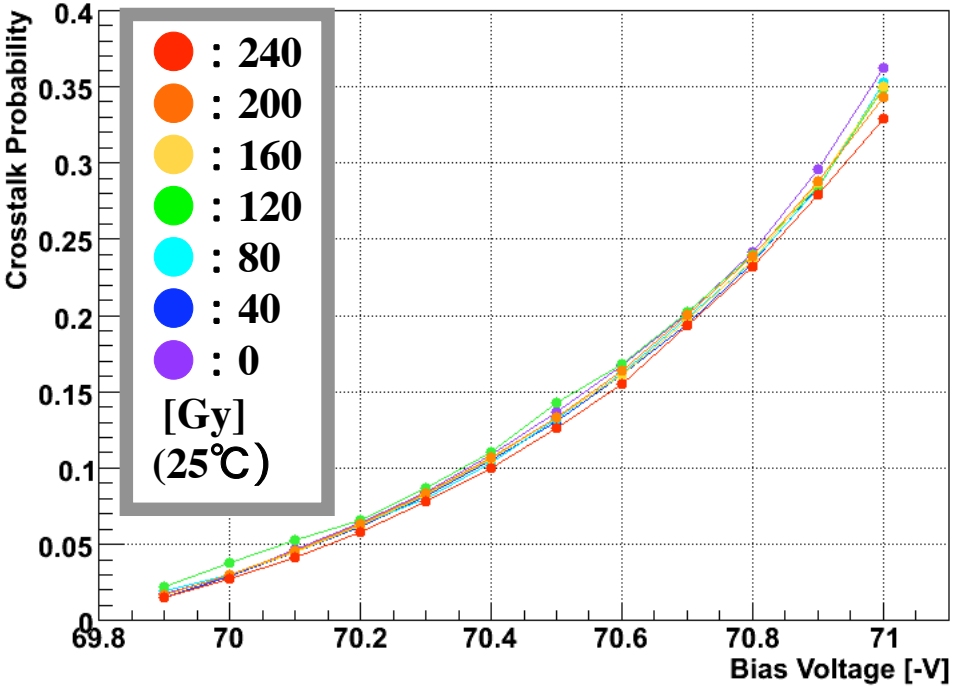


Noise rate, Crosstalk vs Bias voltage

Noise rate vs Bias voltage



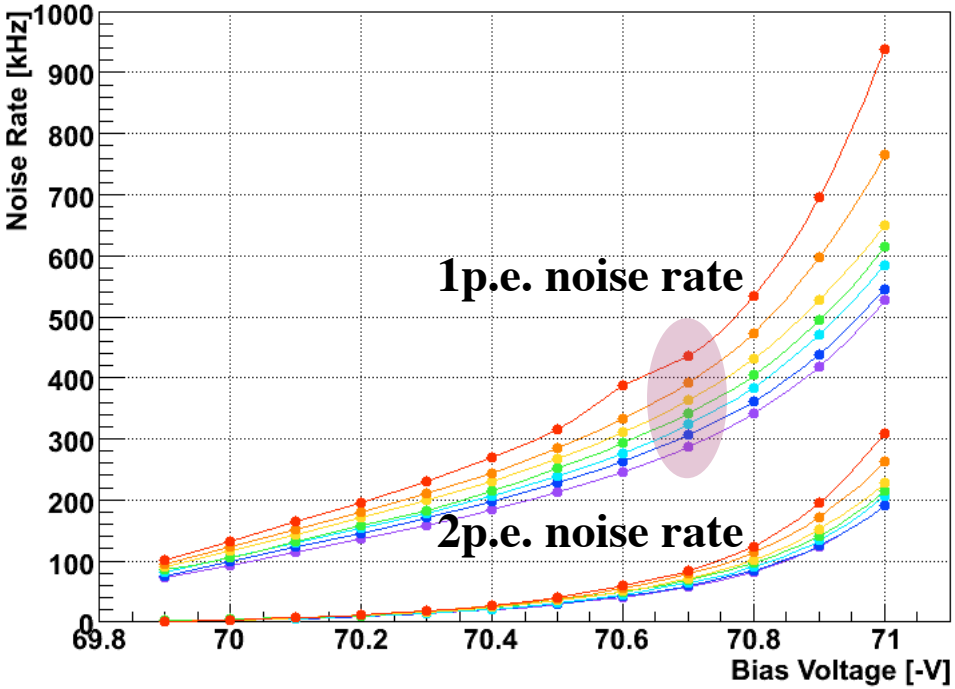
Crosstalk vs Bias voltage



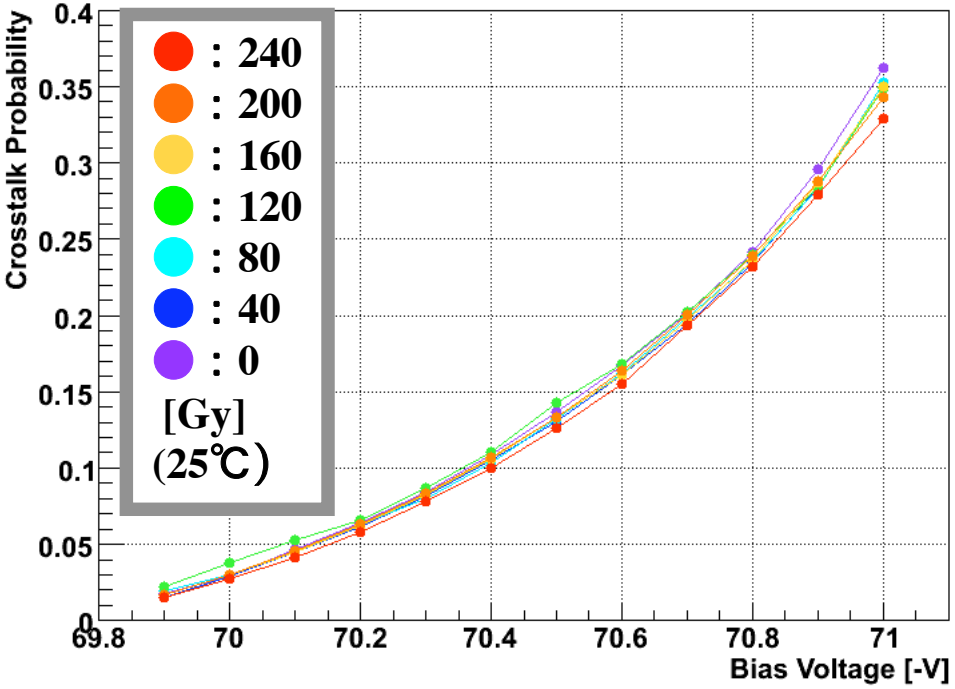
- Noise rate **increased** with radiation
- 1 p.e. noise rate at V_{op} increased ~1.5 times after 240Gy irradiation (280kHz ⇒ 430kHz)
- For crosstalk, **no significant change** was observed

Noise rate, Crosstalk vs Bias voltage

Noise rate vs Bias voltage



Crosstalk vs Bias voltage



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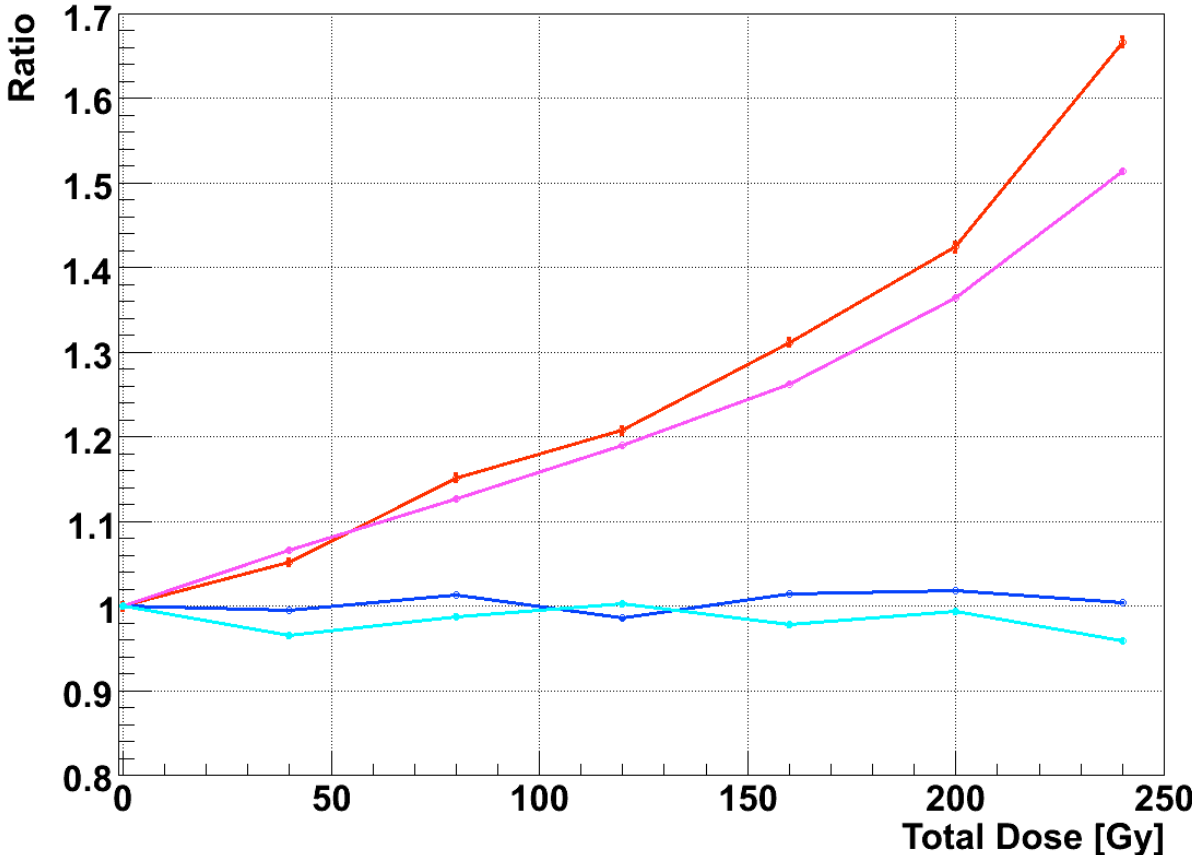
- For crosstalk, **no significant change** was observed

Evaluation of radiation damage

Evaluated radiation damage, assuming 25℃ and 70.7V



● : Leakage Current
● : Gain
● : Noise rate
● : Crosstalk
(25℃, V_{bias}=70.7V)

Leakage Current :
using the second half of
1 hour measurement data
Gain : estimate 70.7V gain
from C_{pixel} and V_0
Noise rate : data at 70.7V
Crosstalk : data at 70.7V

- Leakage current and Noise rate increased as function of total dose
- For Gain and Cross talk, no significant change were observed

Summary

- We studied radiation damage of MPPC using ^{60}Co gamma-ray
- Total 240Gy irradiation accumulated

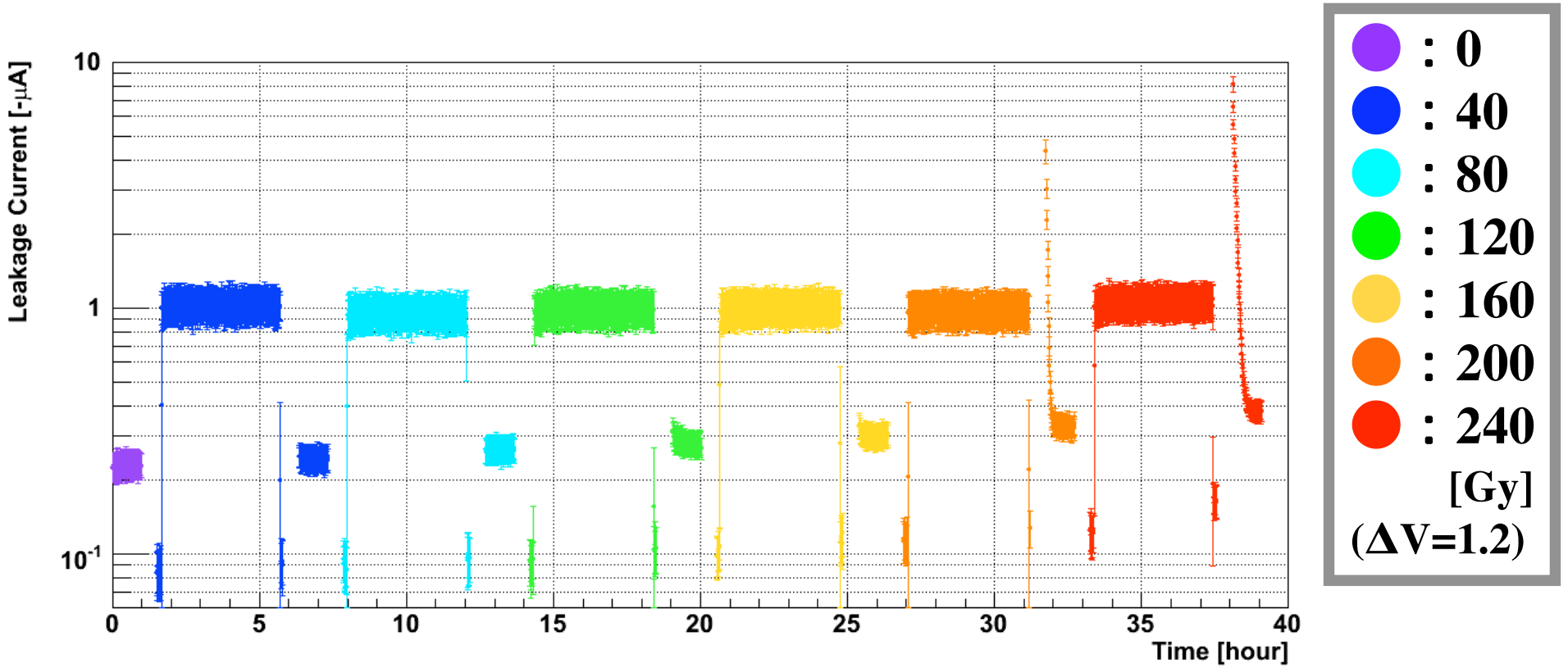
- Leakage current and Noise rate increased as function of total dose
  In condition of 25℃ and V_{op}
  - Leakage current increased ~1.7 times
  - Noise rate increased ~1.5 times
- For Gain and Cross talk, no significant change was observed

- High dark noises were observed during high leakage current after 240Gy irradiation
- We find the localized spot where the high dark noise generated
  - Outer edge of pixels and along the bias line (to see full device)
  - Edge of a pixel (to see 1 pixel)

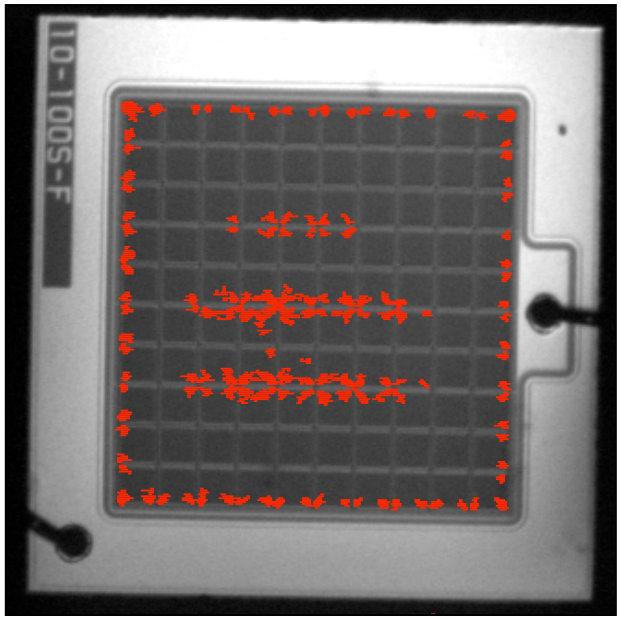
END

Back up

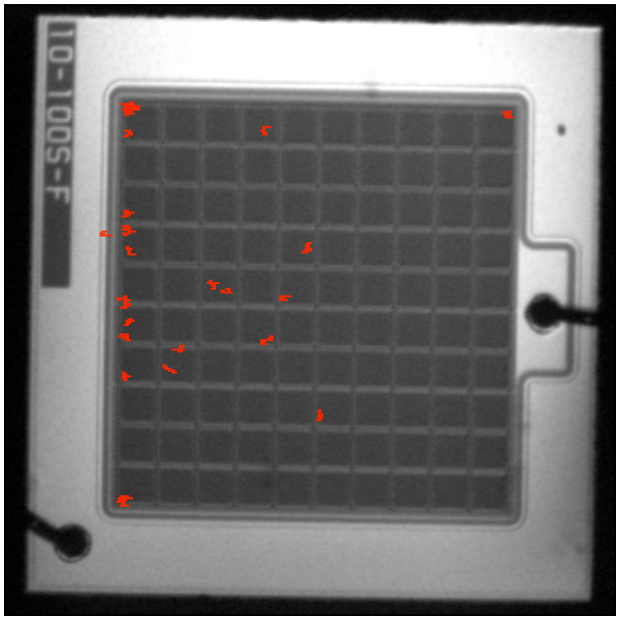
All data of leakage current



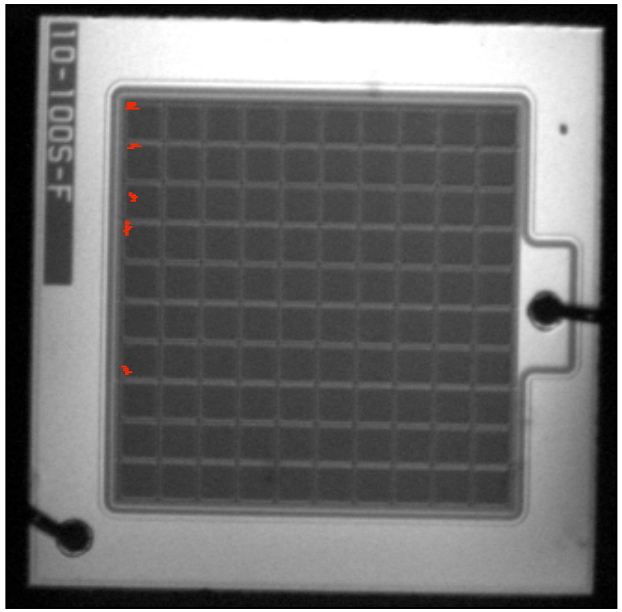
Annealing effect of infrared emission



Just after voltage supplied

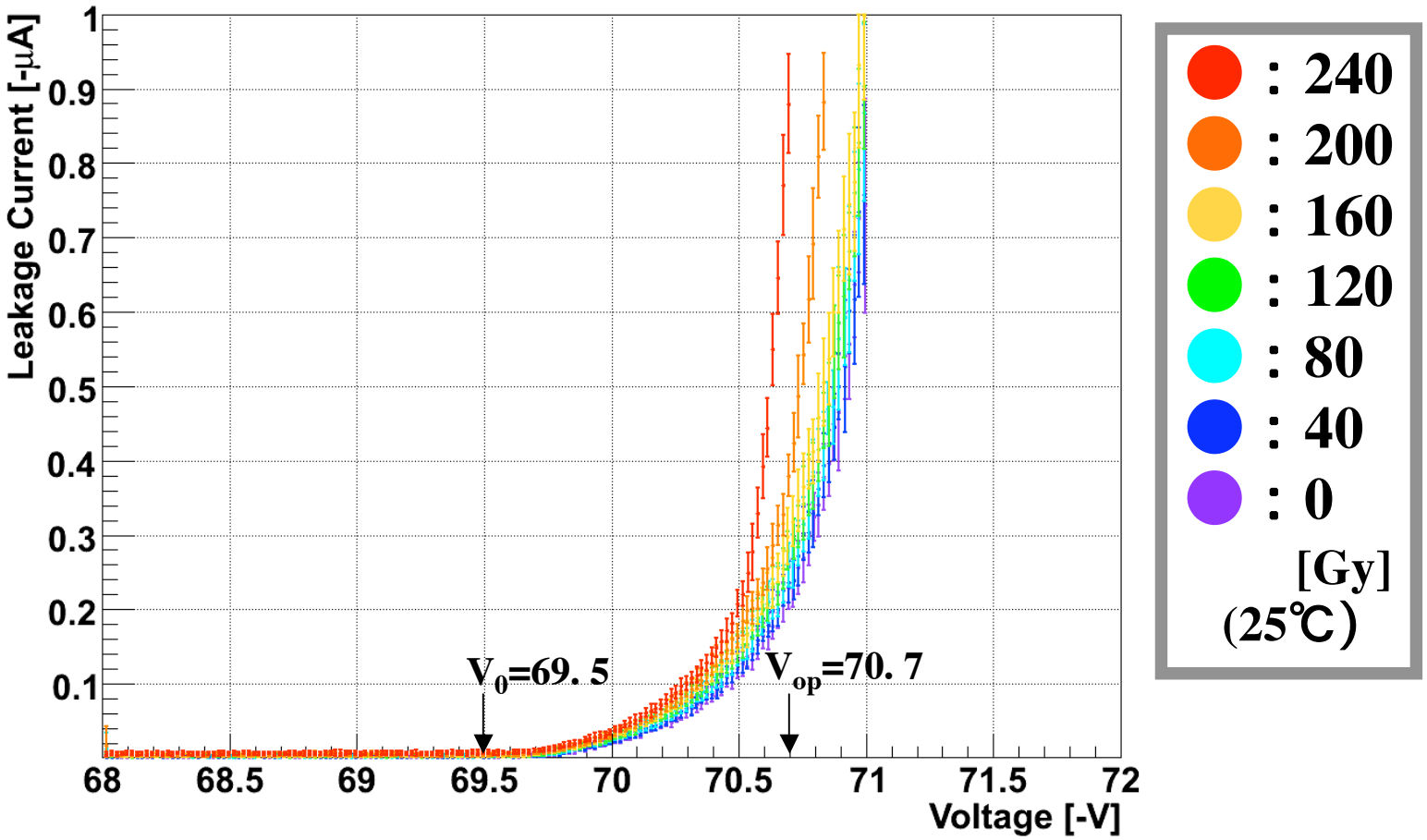


After 5 min.



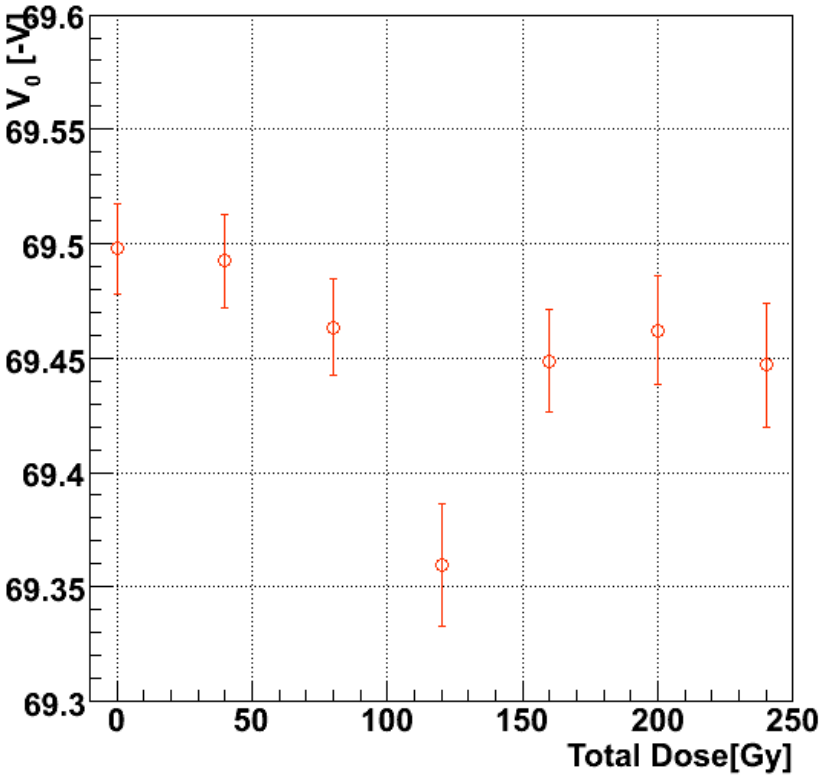
After 10 min.

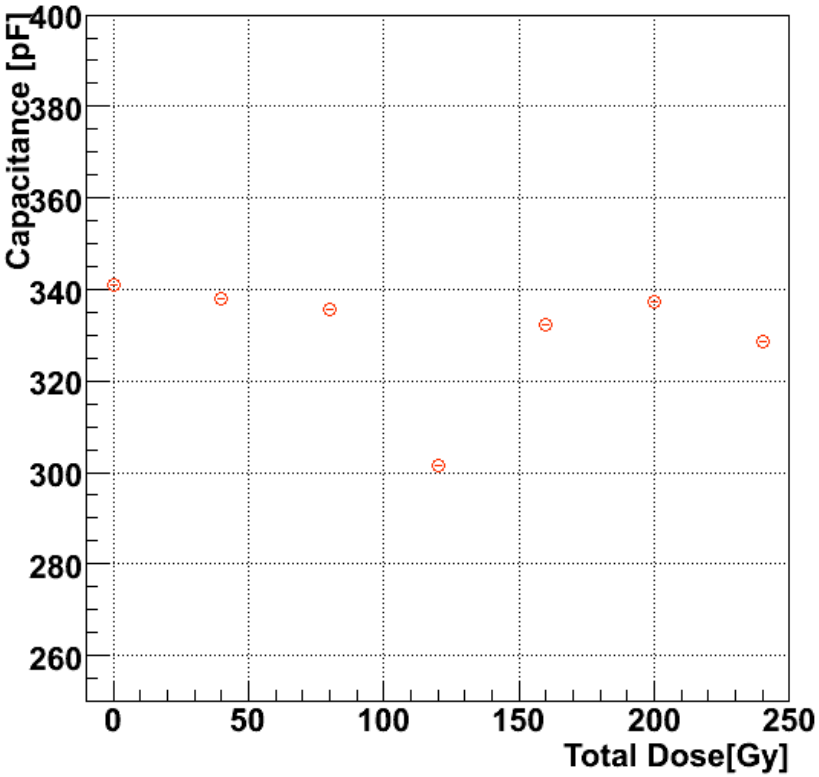
I-V curve



- Leakage current increased with irradiation
- Sudden increase was observed after 200 Gy and 240 Gy irradiation

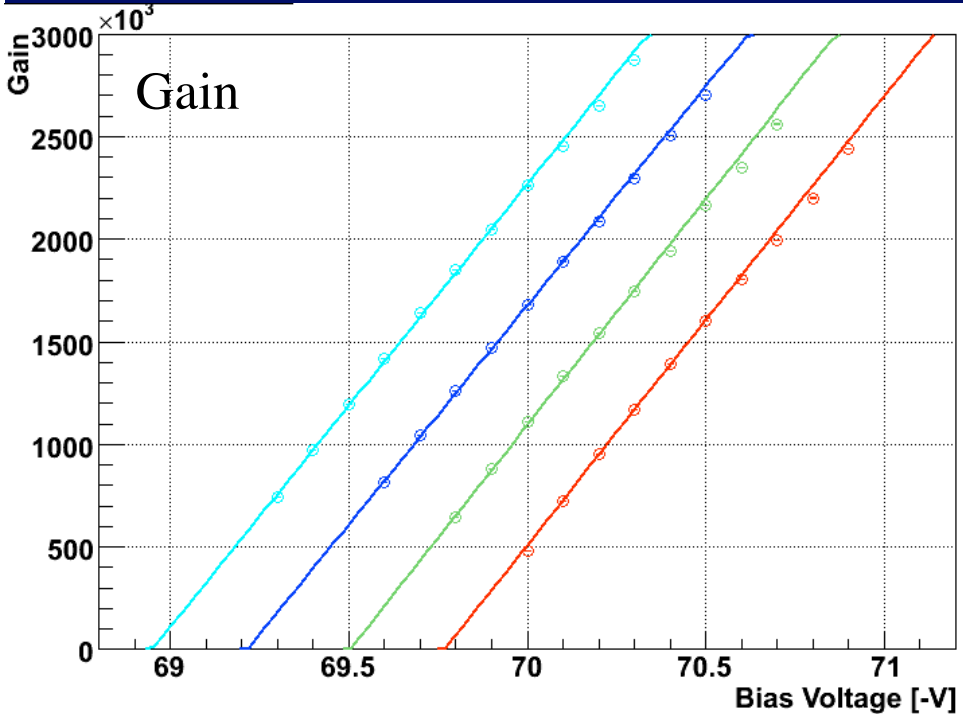
V_0, C_{pixel} vs dose rate

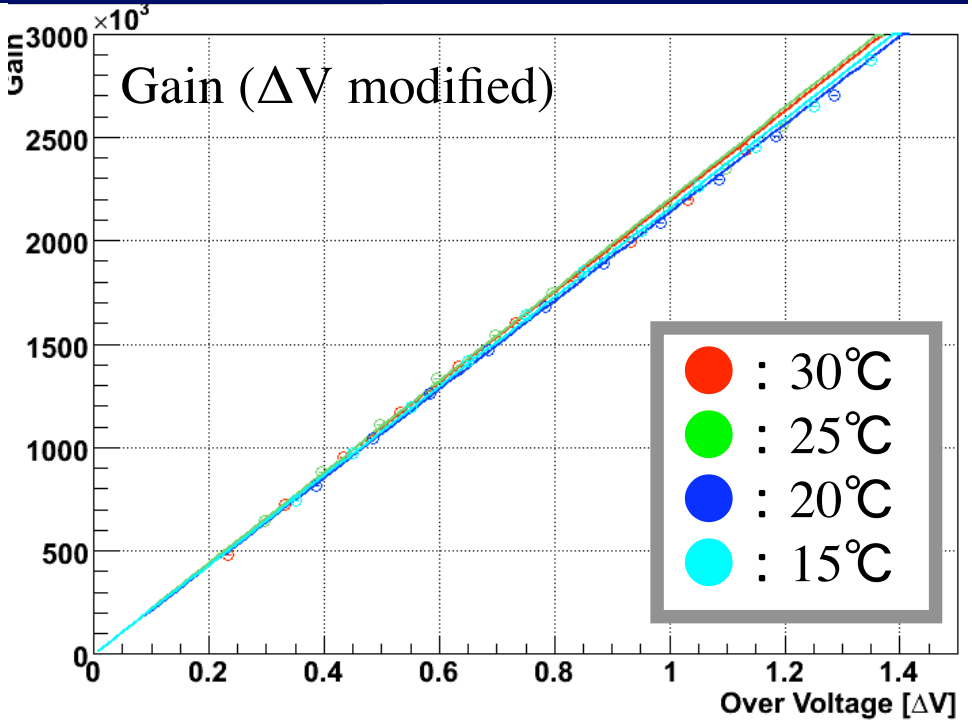


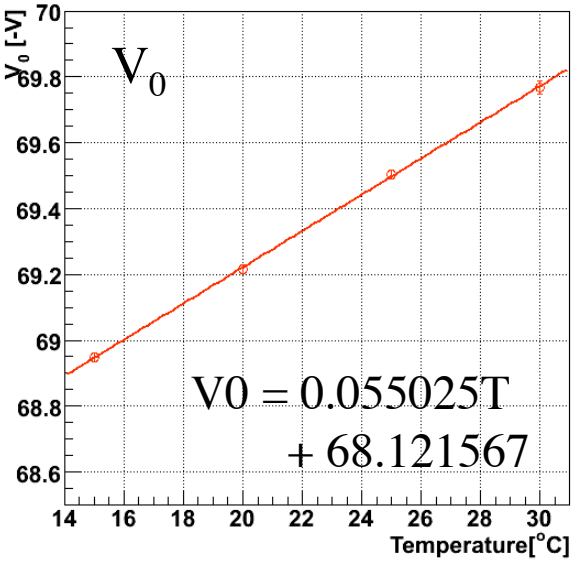


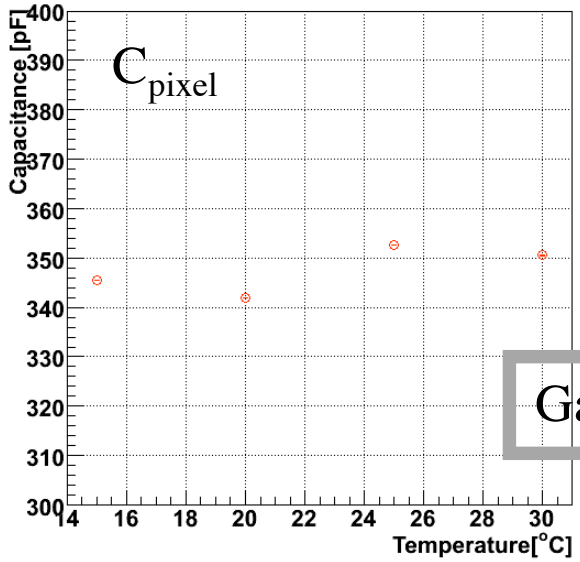
- **No significant change was observed in both**
- **There is a error in temperature control during 120 Gy measurement**

Temperature dependence (1)



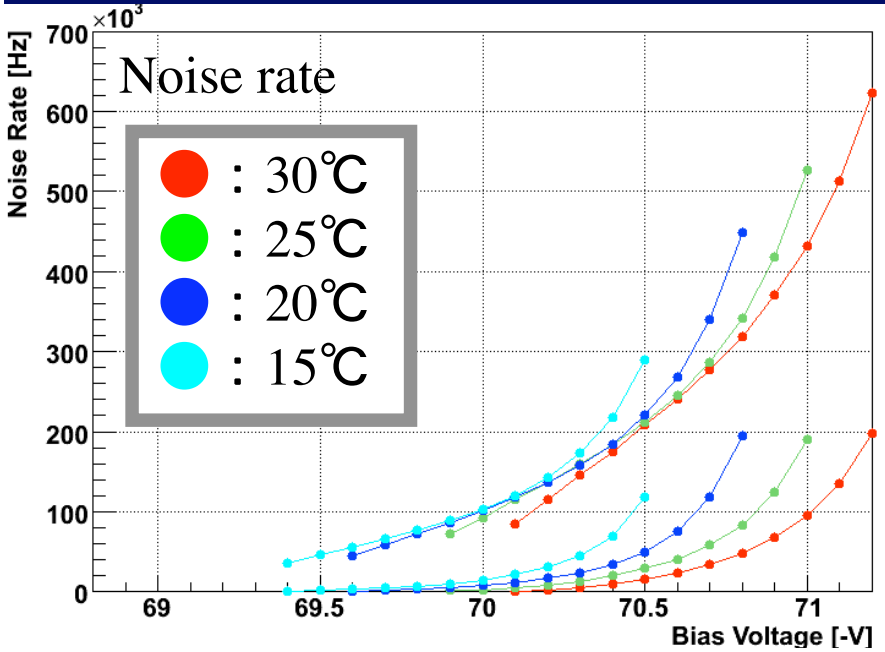


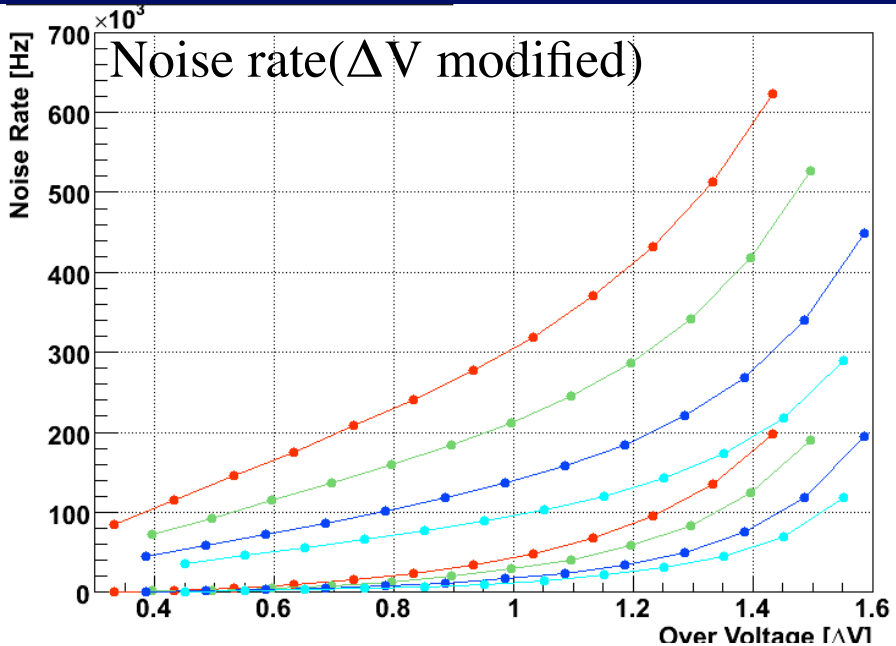


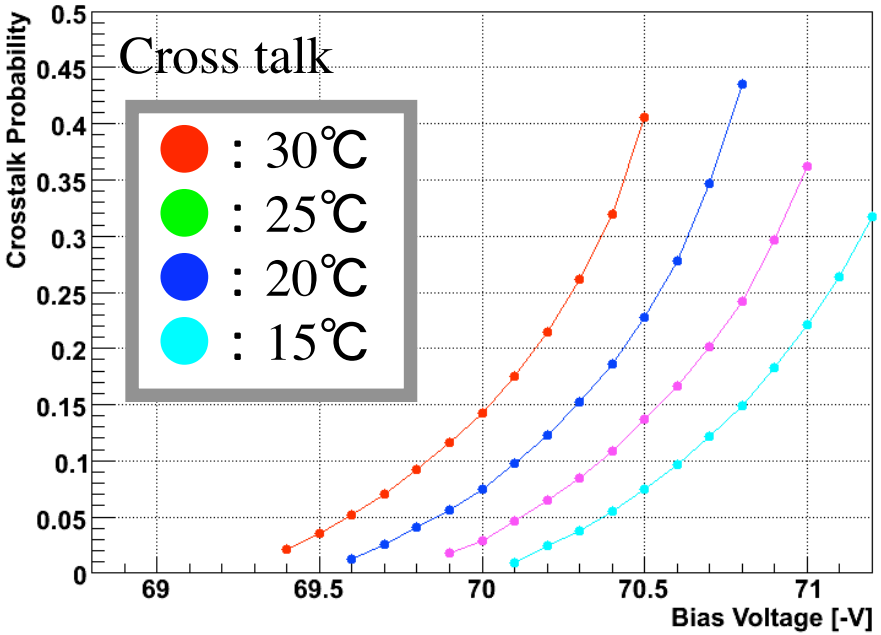


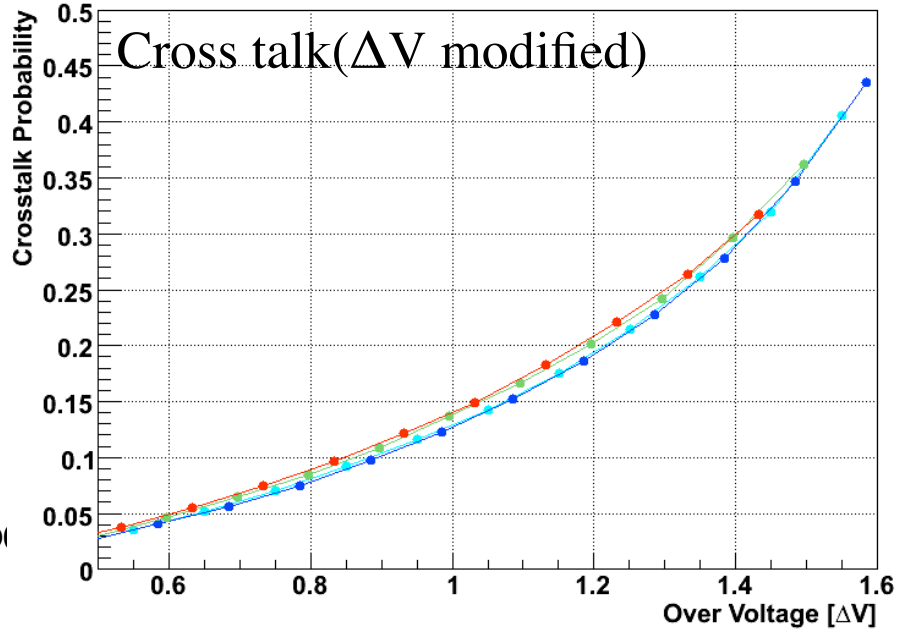
$$\text{Gain} = C_{pixel}(V_{bias} - V_0) / e$$

Temperature dependence (2)

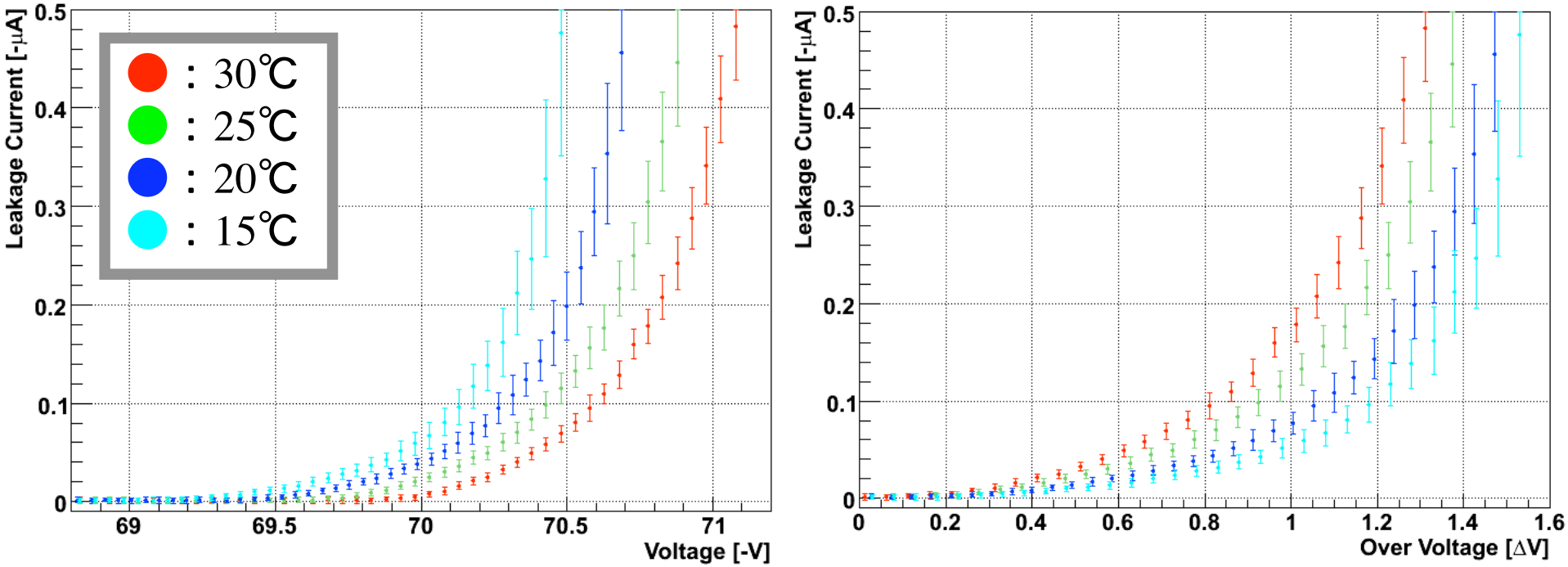








Temperature dependence (3)



- **Comparing bias voltage (=70.7V), Leakage current is 30<25<20<15℃**
- **Comparing over voltage (=1.2V), Leakage current is 15<20<25<30℃**