Radiation Hardness Tests of SiPMs with a Proton Beam for Future Satellite Missions.

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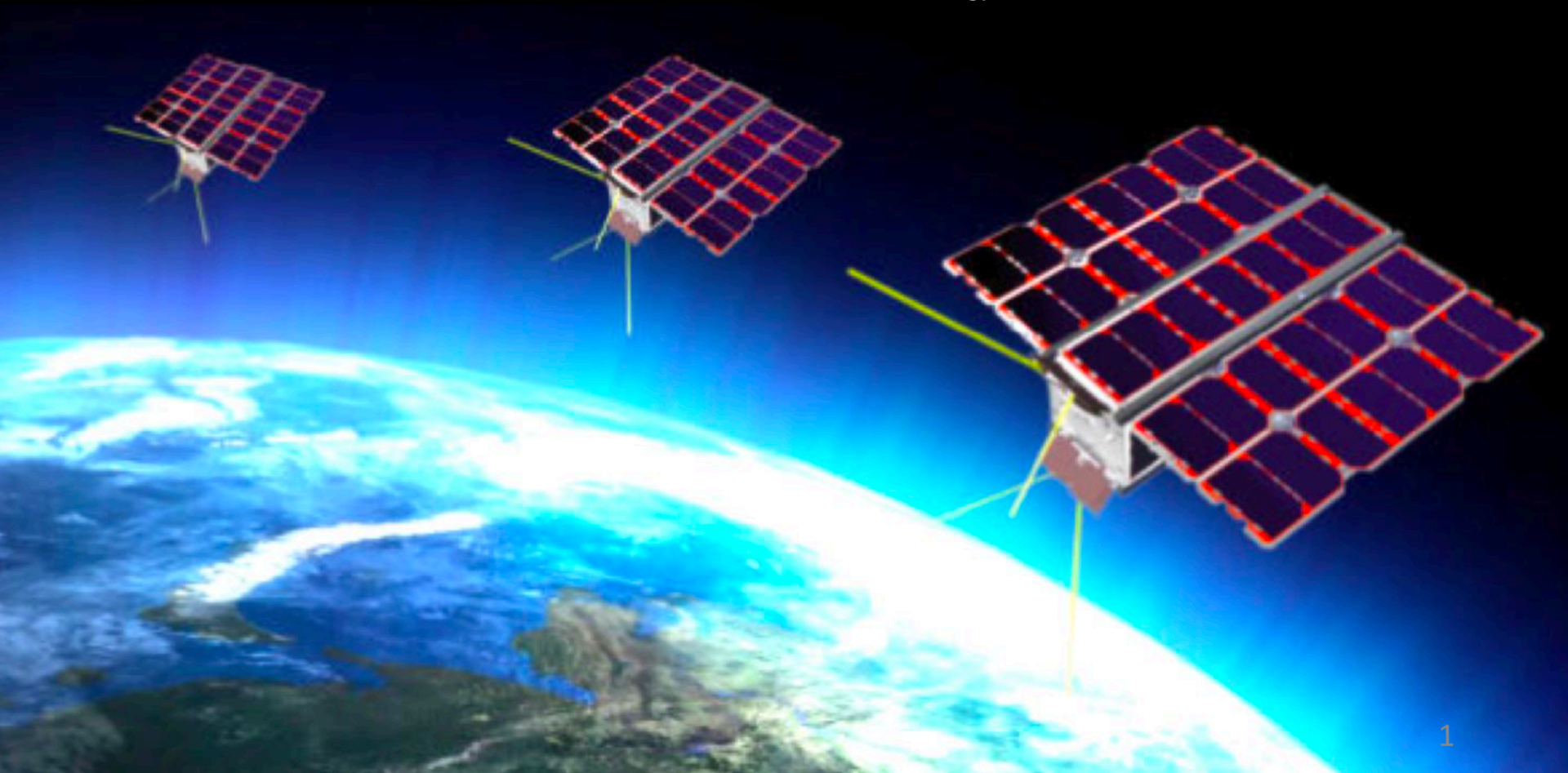
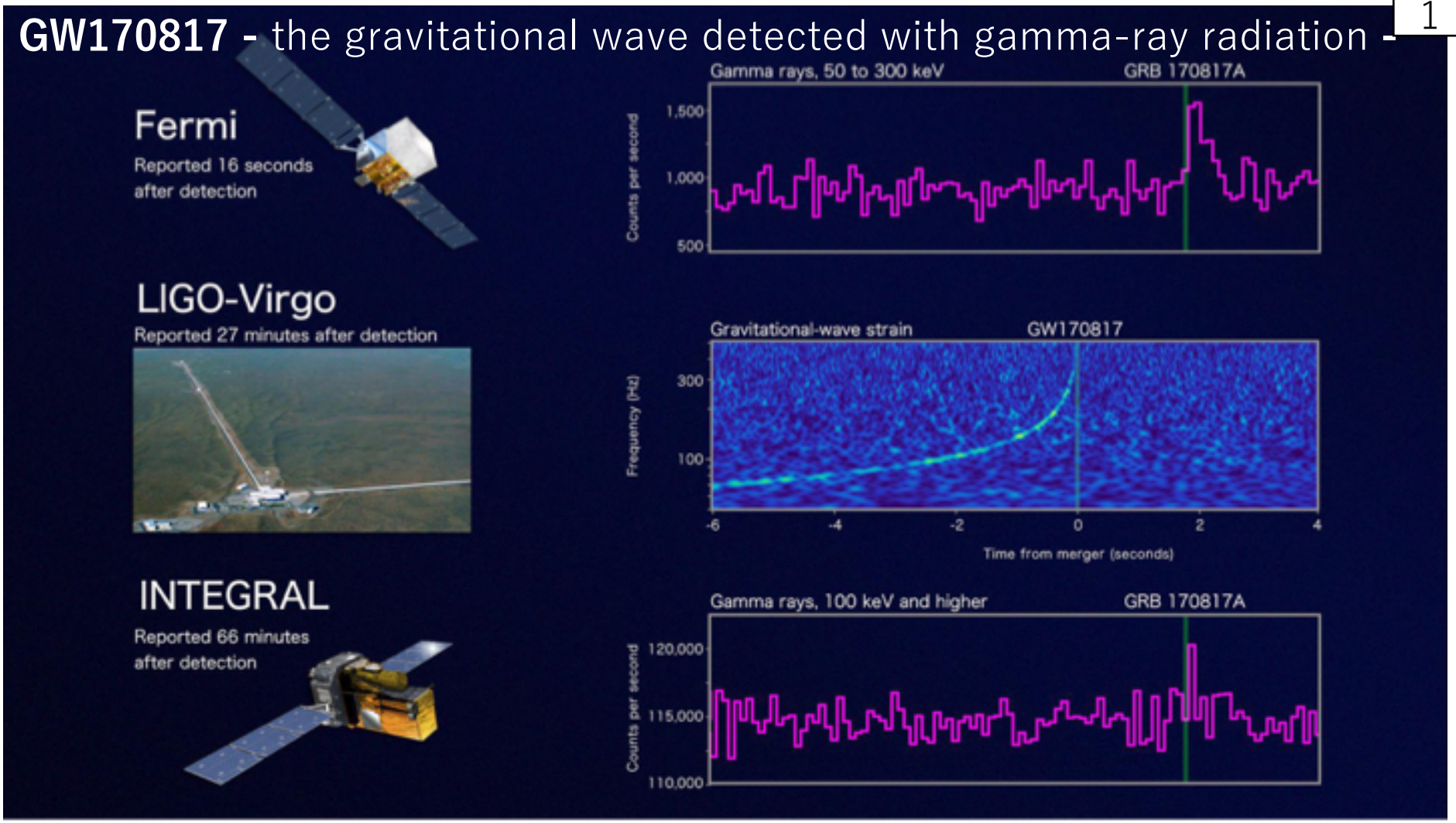


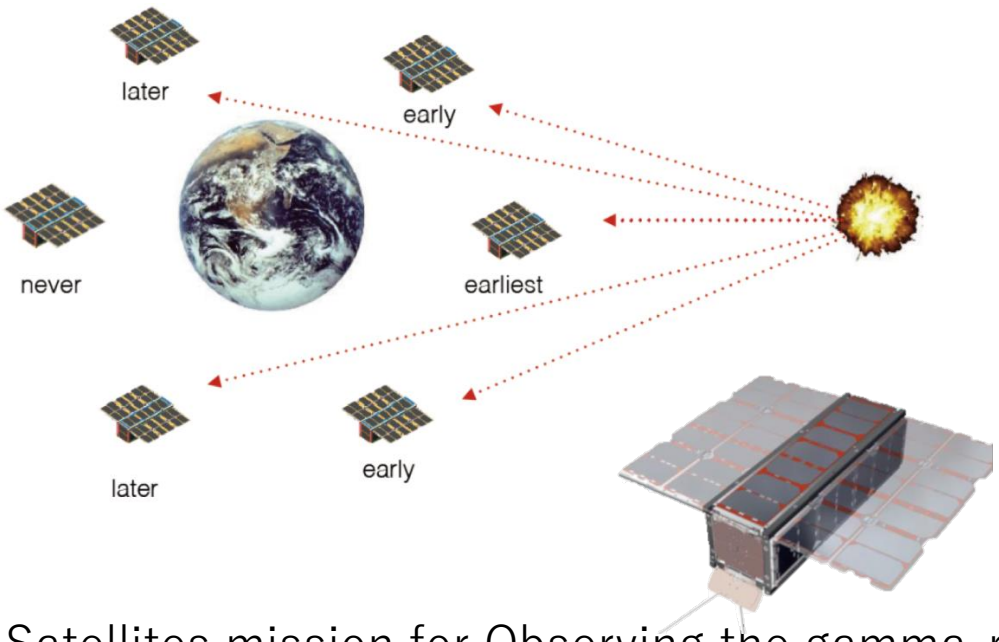
GW170817 - the gravitational wave detected with gamma-ray radiation **-**

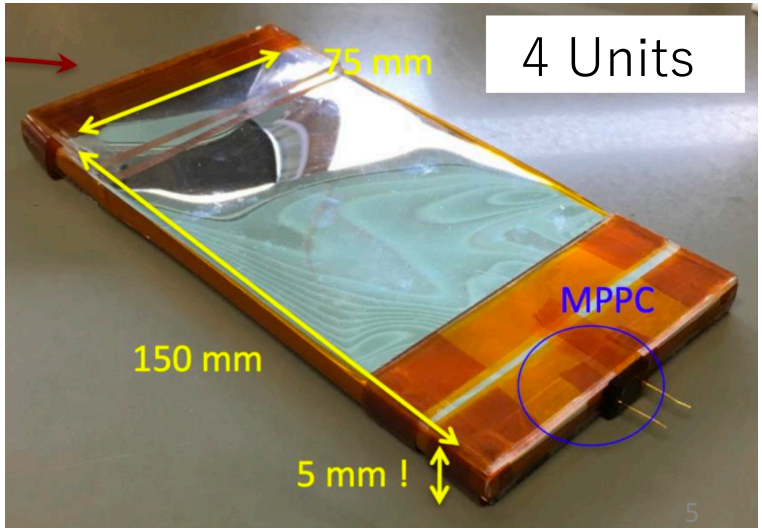


- GW170817 was detected!
- Localization accuracy of the Gravitational detector is ~ 10 degree.
- We don't have the satellite can observe all sky with better localization.

Scientific requirement: the satellite with **wide FoV** and **Localization accuracy**

CAMELOT :
CubeSats Applied for MEasuring and LOcalizing Transients





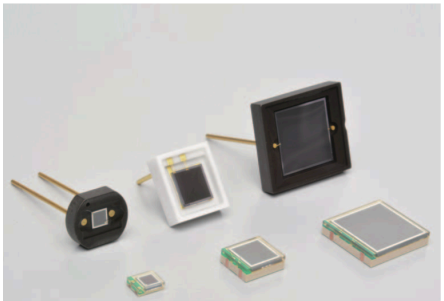
PI: Norbert Werner(Eötvös Univ.)

- Satellites mission for Observing the gamma-ray transients.
  - ⇨Covering **whole of the sky** with **many small CubeSats**.
  - ⇨Determine the transient **position accurately** by triangulation method.
    (~ 10 arcmin.)
- **Large effective area** and **low energy threshold** are the key.
- Small satellites require Low power consumption and compactness.
  - →**Scintillation detector** consists of **large Tl:CsI scintillator** and **Si-PMs.**
    This autumn, we are planning the balloon flight for detector tests.

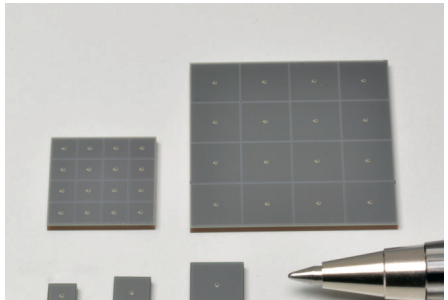
Photon Detector: SiPM(MPPC)

Low bias voltage(<60 V), **compact**(~1 cm) → **Suitable for small satellite**
We were planning to use **S13360** by Hamamatsu→ New model **S14160**

Which is suitable for **CAMELOT** mission.



S13360-6050CS



S14160-6050HS

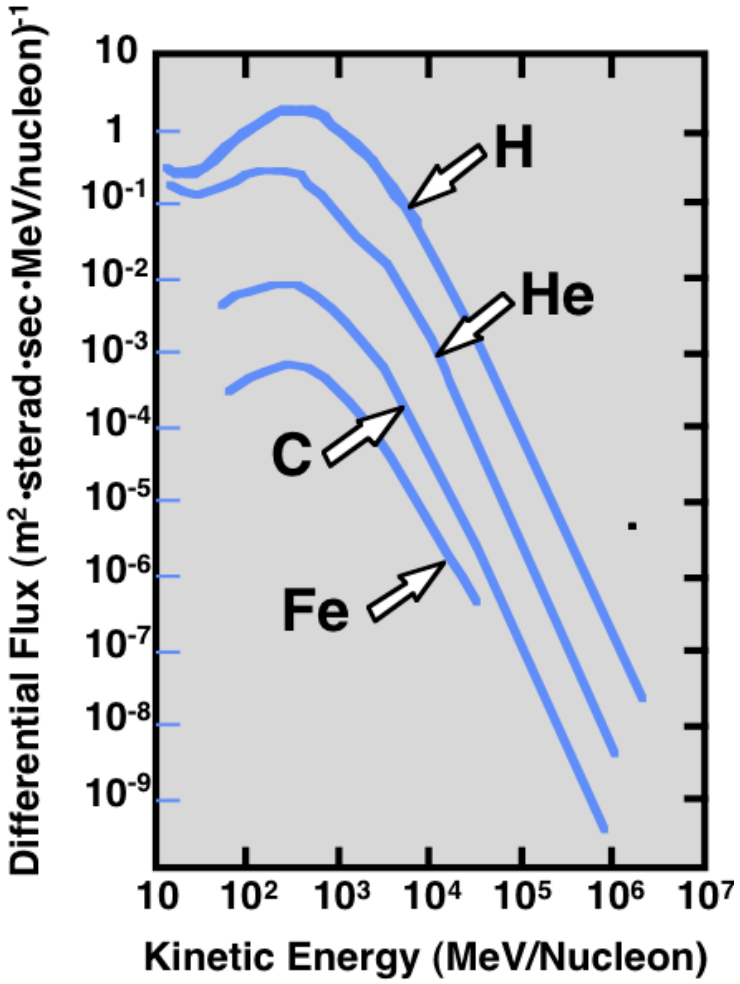
	Detection Eff. (%)	Gain (10^6)	Dark Current (uA)	Operation Bias (V)
S13360-6050CS	40	1.7	0.388	54.4
S14160-6050HS	50	2.5	1.63	41.0

- **S13360** series has **lower dark current**.
- **S14160** has higher detection efficiency and gain → **Big Signal?**
- **S14160** has lower operating voltage → Easy for developing a power supply

Radiation damage for SiPM

- In the satellite orbit (Low Earth Orbit)
  → Proton with the average energy of ~100 MeV.

- Elastic scattering to the Si atom of SiPM…
  →Increase the **dark current** (~1000 x @1 krad)
  →Increase of **power consumption**
  →**Energy Threshold** becomes worse



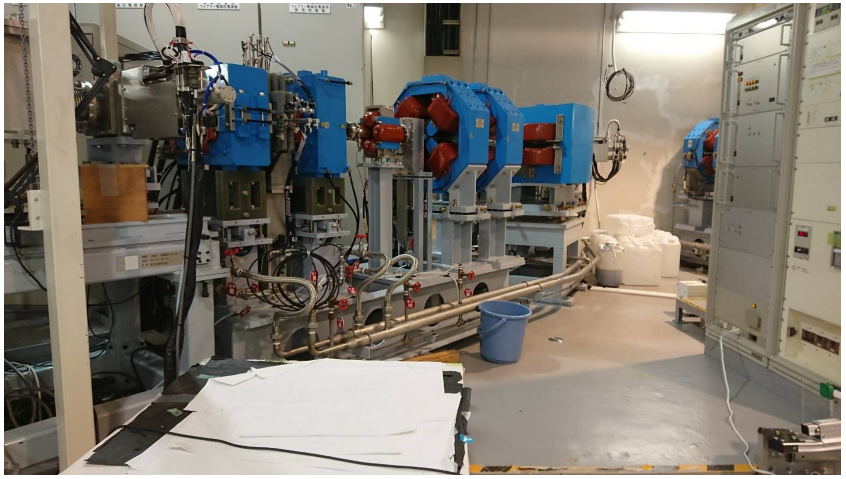
W. Schimmerling, J. W. Wilson, F. Cucinotta, and M-H Y. Kim.

→Detection of less **number of gamma-rays.**

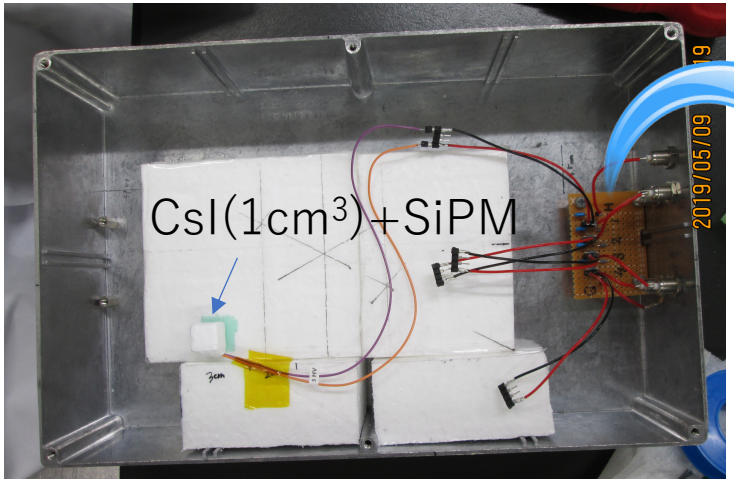
→**GRB localization accuracy becomes worse.**

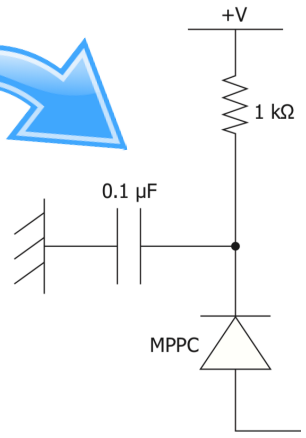
Proton hardness test @The Wakasawan Energy Research center.

- Proton energy : 200 MeV
  Total Dose:
  up to 5000 rad (50 Gy)
  ~ 5 years in orbit.
  →~ 3 x 10^{10} 1 MeV n_{eq}

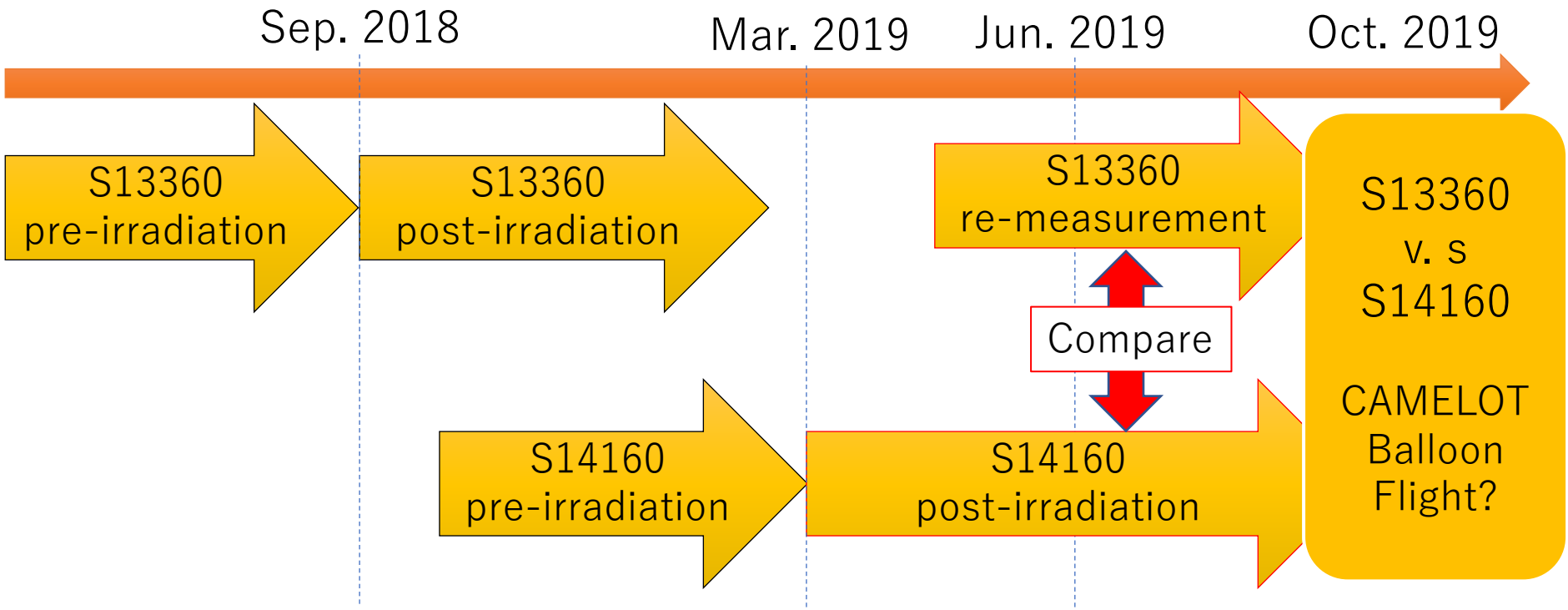


- ^{241}Am Spectra measurement w/ TI:CsI
  → Evaluate the energy threshold.
- I-V and spectra are monitored ~ half a year at Hiroshima Univ for S13360.
  → Recovery test(annealing@room temperature)?





Measurement Process



▶ We irradiate the proton beam for S13360 and S14160 in separate period.

▶ The measurement setups for “S13360 post-irr.” and “S14160 post-irr.” are different.

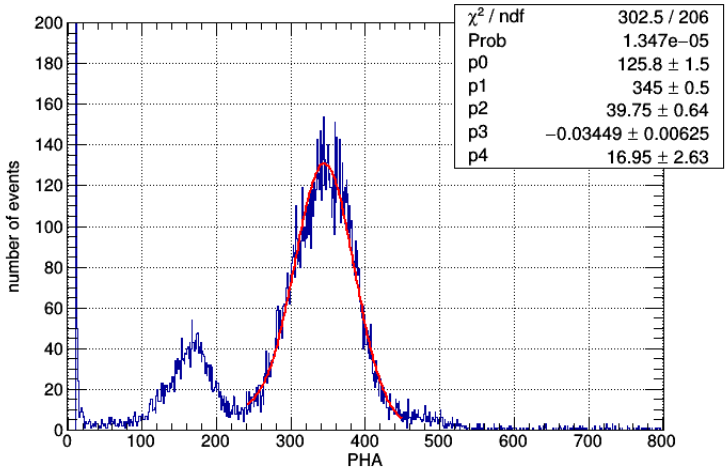
▶ We compared the “**S13360 re-meas.**” and ”**S14160 post-irr.**”

➡ Which is suitable for CAMELOT mission?

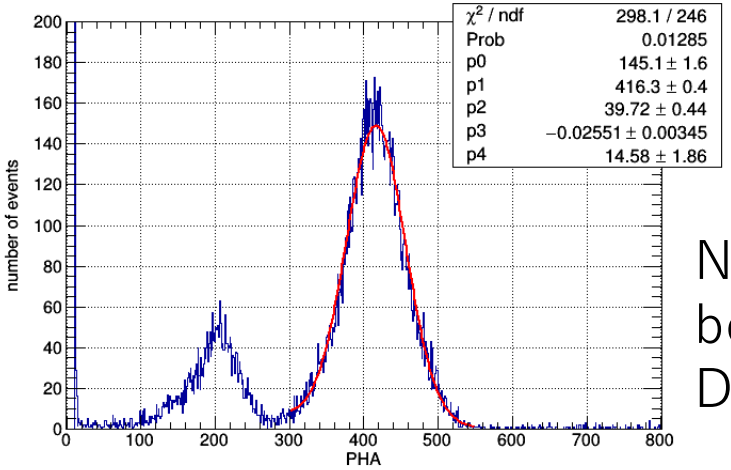
Spectra Before Irradiation -- In detail, poster by H. Takahashi --

- We measured ^{241}**Am** spectra with the **undamaged** S13360 and S14160

S13360-6050CS



S14160-6050HS

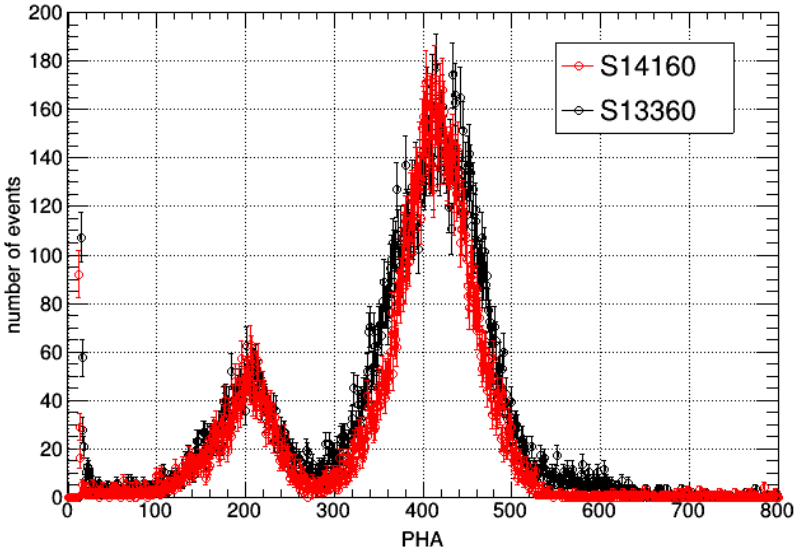


Temperature : +20 °C

Bias Voltage :

S13360 : V_{op}=55.4 V(0.229 uA)

S14160 : V_{op}= 41.0 V(0.909 uA)



Not significant difference in energy resolution between S13360 and S14160.

Dark currents are consistent with datasheet.

Dark Current Right After Irradiation (S13360 vs S14160)

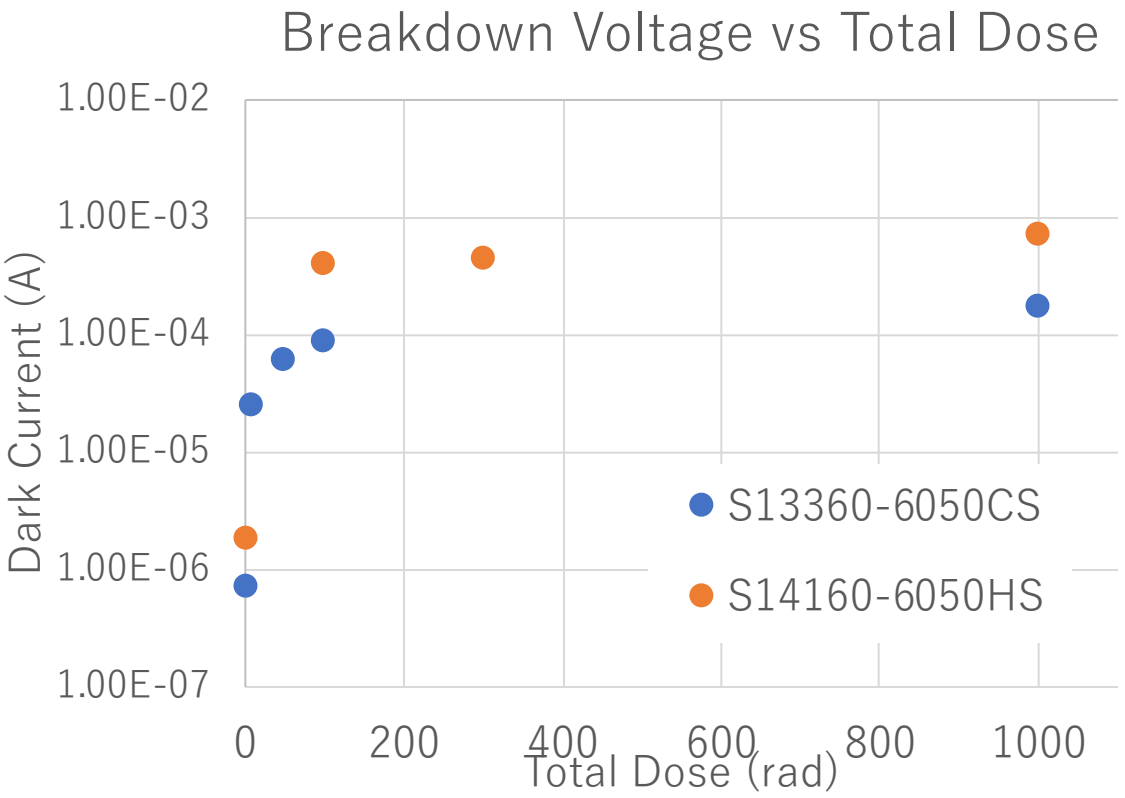
- Comparison of dark current measured at right after irradiation.

Vop = 55 V (S13360)
Vop = 41 V (S14160)
} ~ Recommended voltage

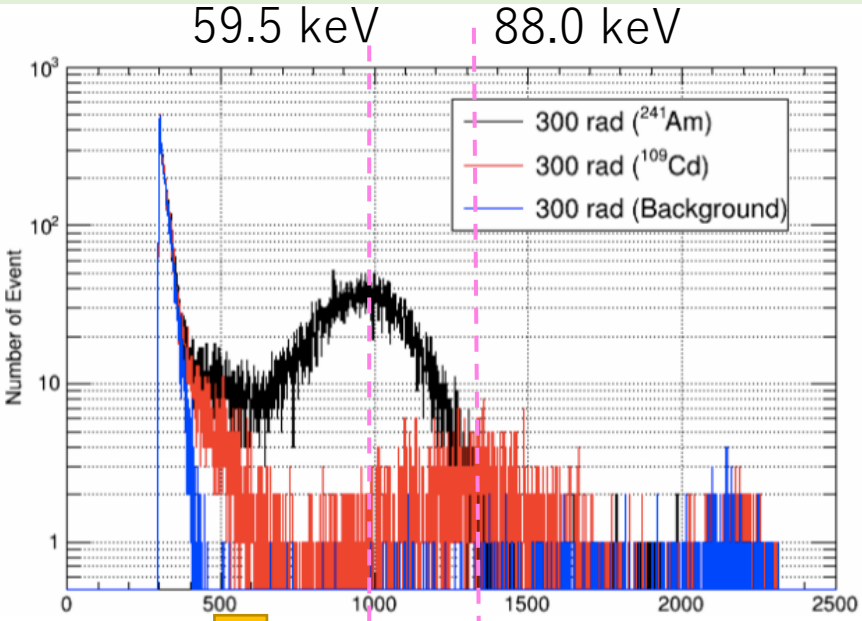
- Voltage drop should be considered for over 100 rad.

- S14160 has higher dark current than S13360. (Consistent with datasheet)

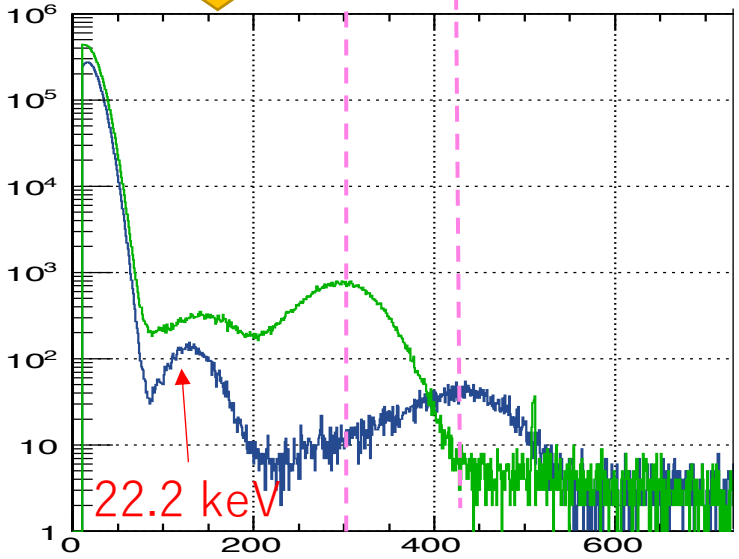
- The variation ranges of the dark current are same between S13360 and S14160.

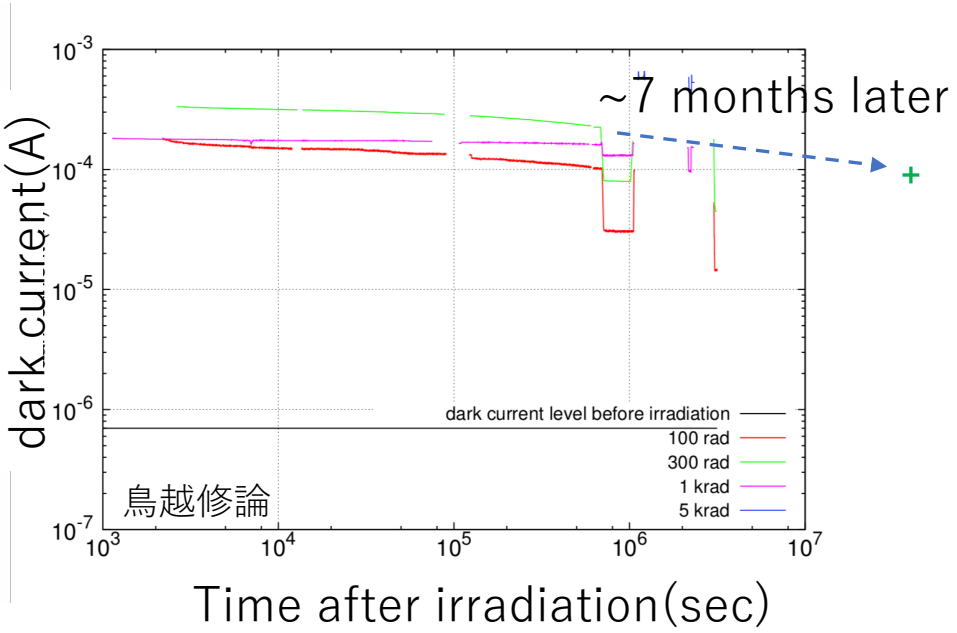


Spectrum of right/7months after the proton irradiation for S13360-6050CS



7 months later..





▶Spectra

22.2 keV photo peak (^{109}Cd) is recognized.

▶Dark current

2×10^{-4} A → 9×10^{-5} A

→Recovered?

Need to evaluate more quantitatively.

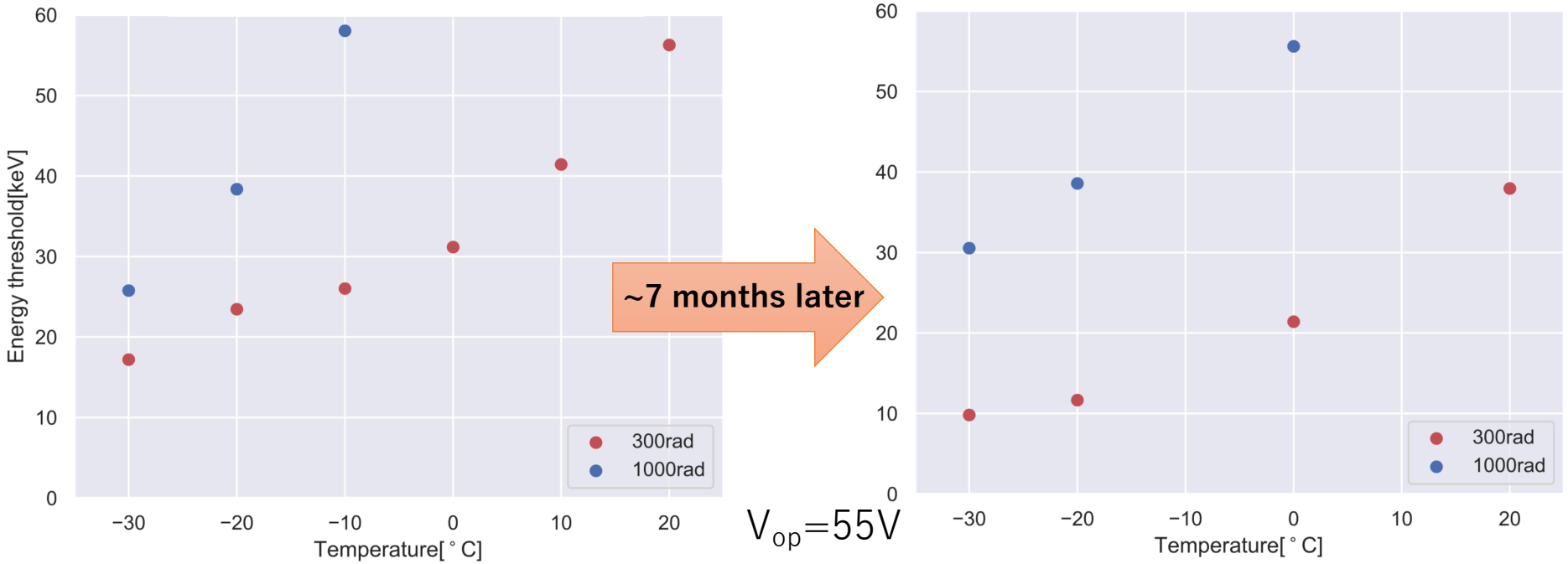
→Energy threshold.

Energy Threshold of right/7months after the proton irradiation for S13360-6050CS

▶ Energy threshold : 4-sigma value of gaussian fit for the dark current noise part in the spectra.

S13360, right after irradiation

S13360, 7 months after irradiation



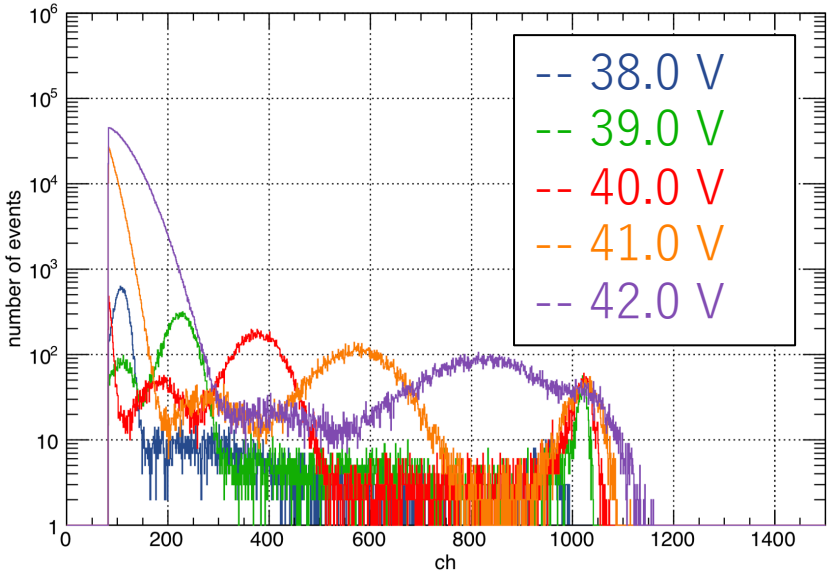
▶ We find the **recovery** of **energy threshold** for both of 300 rad and 1000 rad and for all temperature range(-30 °C～+20 °C)

→**Annealed** in 7 months of room temperature storage!

S13360-6050CS(7 months after irradiation) vs S14160-6050HS(right after irradiation)

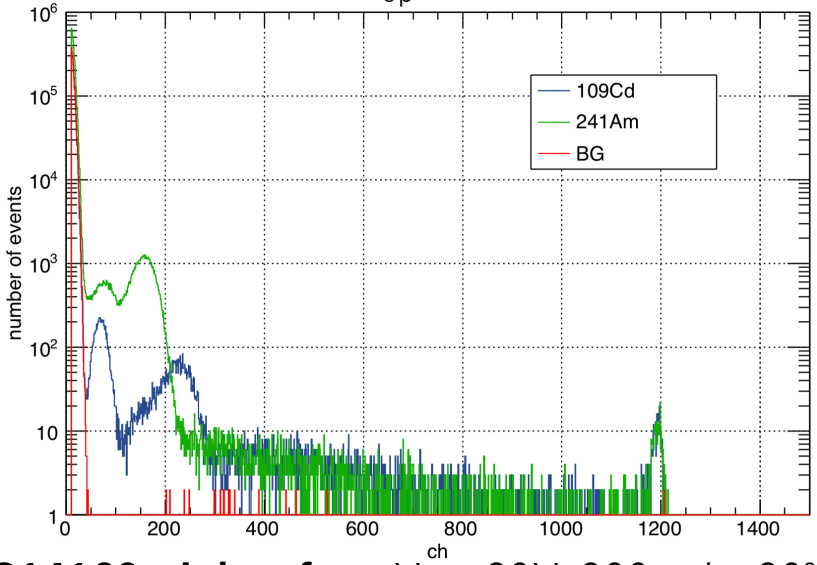
▶ We measure the spectra for various bias voltage, and we fond the voltage which has the **best S/N**.

S14160, right after irradiation,
300 rad, -30 °C, Bias validation(38 V ~ 42 V)

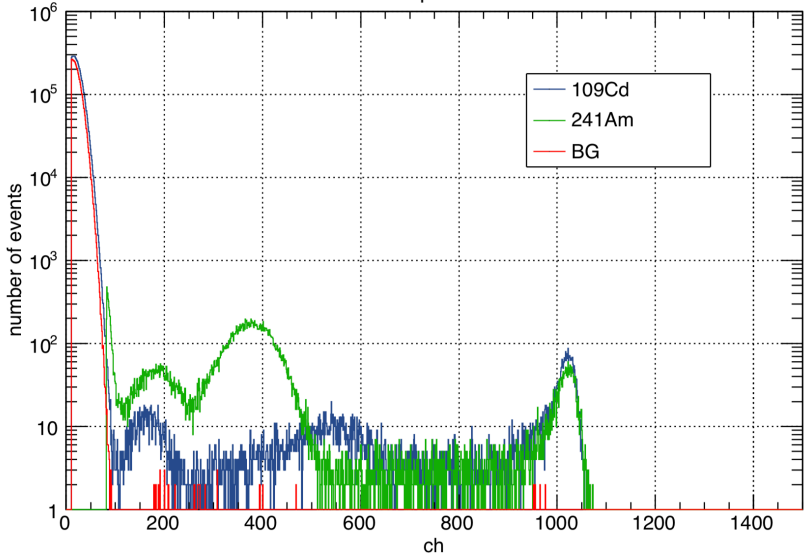


We calculate the **energy threshold** and evaluate quantitatively.

S13360, 7 months, V_{op}=52 V, 300 rad, -30 °C



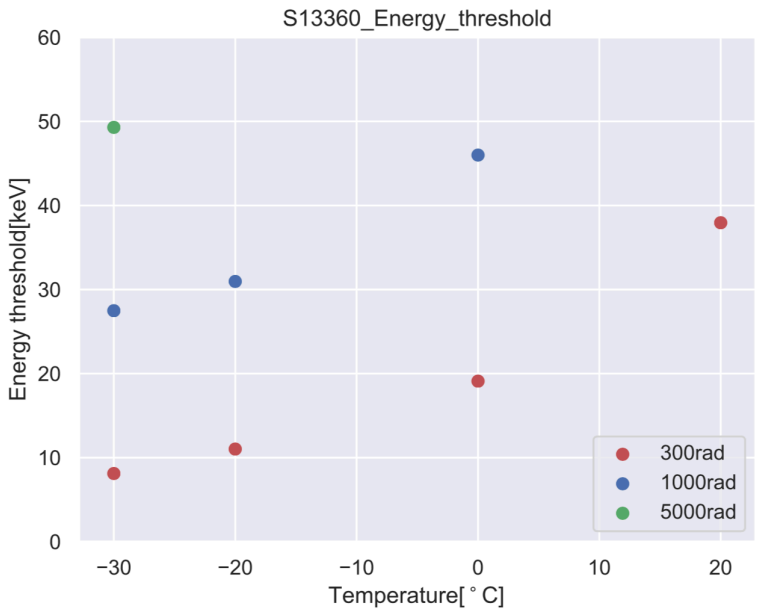
S14160, right after, V_{op}=39V, 300rad, -30°C



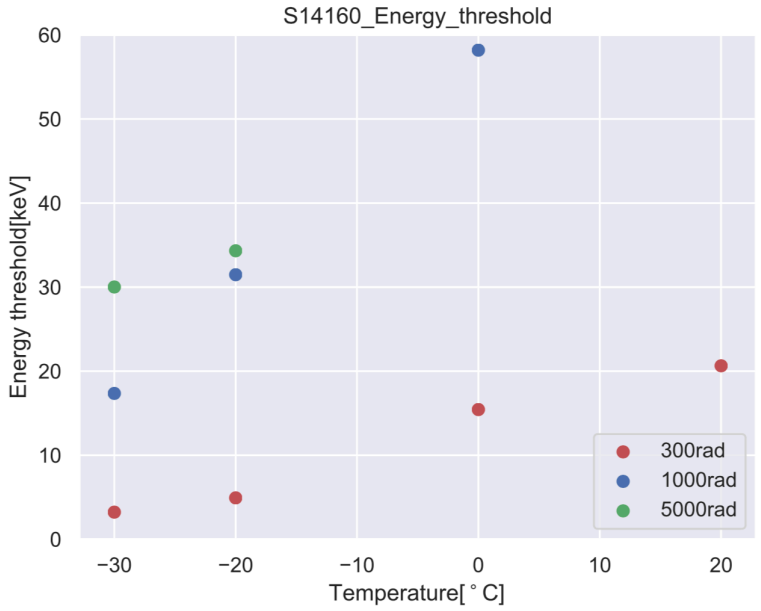
S13360-6050CS(7 months after irradiation) vs S14160-6050HS(right after irradiation)

Compare the energy threshold between **S14160(right after irradiation)** and **S13360(7 months later)**.

S13360, 7 months later,
V_{op}= Voltage which has the best S/N



S14160, right after irradiation,
V_{op}= Voltage which has the best S/N



- S14160 has better energy threshold in case of 300 rad and 5000 rad.
- In the case of 1000rad, S13 and S14 have same level of energy threshold.
  - →S14160 has the almost same performance with RCOVERED S13360.
  - →S14160 is the good candidate for CAMELOT mission.

Conclusion and Future work

▶We are planning the CAMELOT mission that have wide FoV and accurate Localization.

▶ Our detector consists of Tl:CsI scintillator and SiPM for low power consumption and compactness.

▶ We have investigated which is suitable for the CAMELOT mission, S13360 and S14160.

▶ Not significant difference in S13360 and S14160 for pre-irradiation.

▶ Dark current gets worse after the proton irradiation.

▶ We found the recovery for S13360 in 7 month storage in room temp.

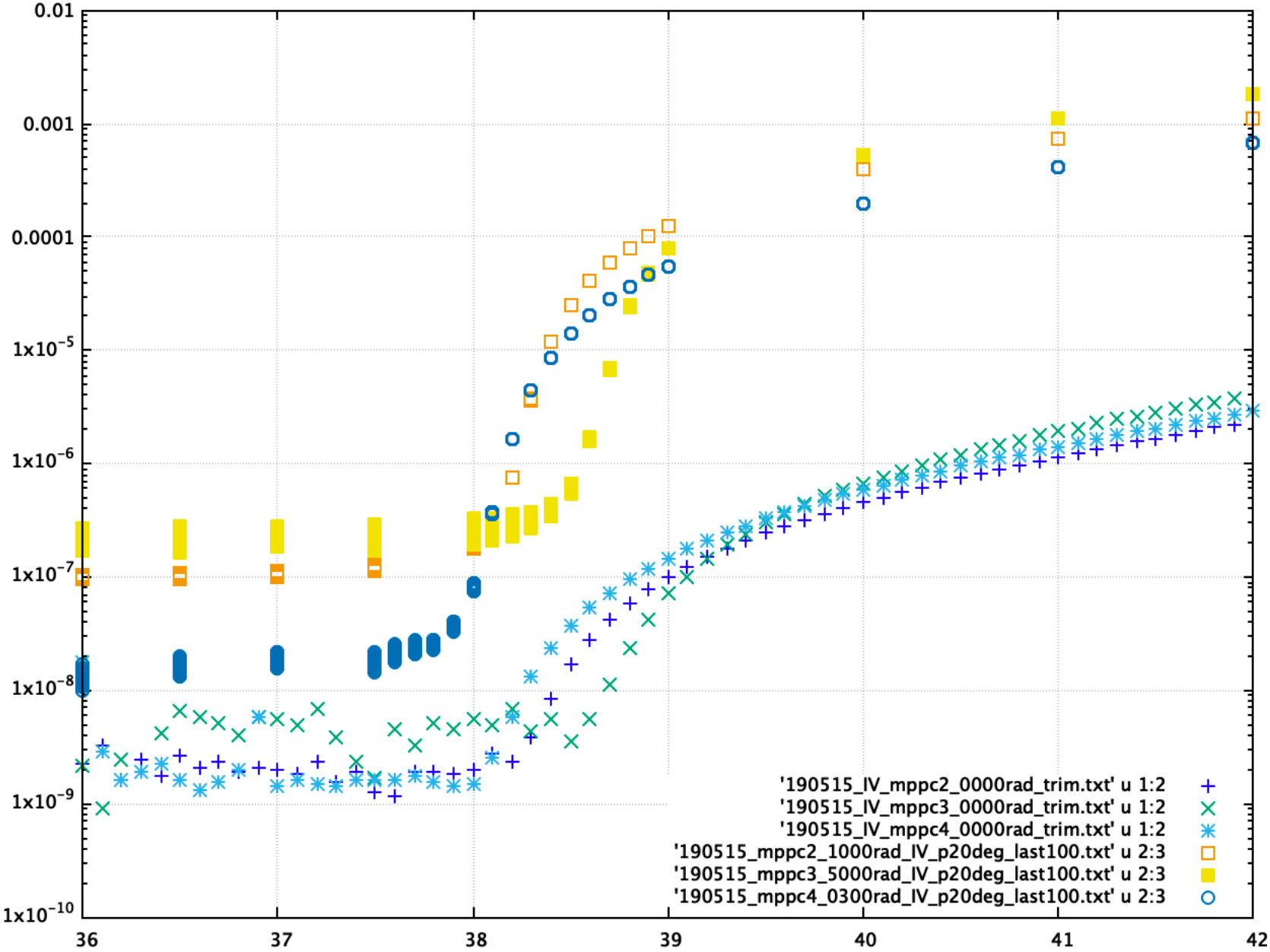
▶ Not significant difference b/w S13360 in 7month later and S14160 right after irradiation.

→We are considering to use S14160 for CAMELOT mission。

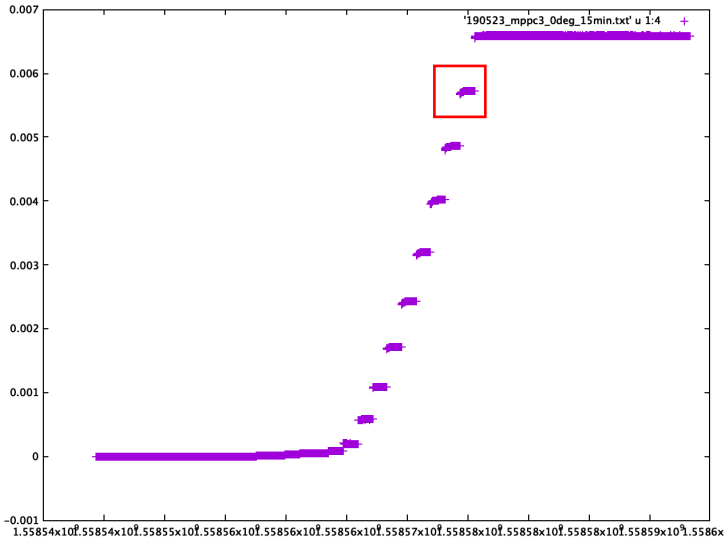
▶ We will confirm the annealing effect for S14160.

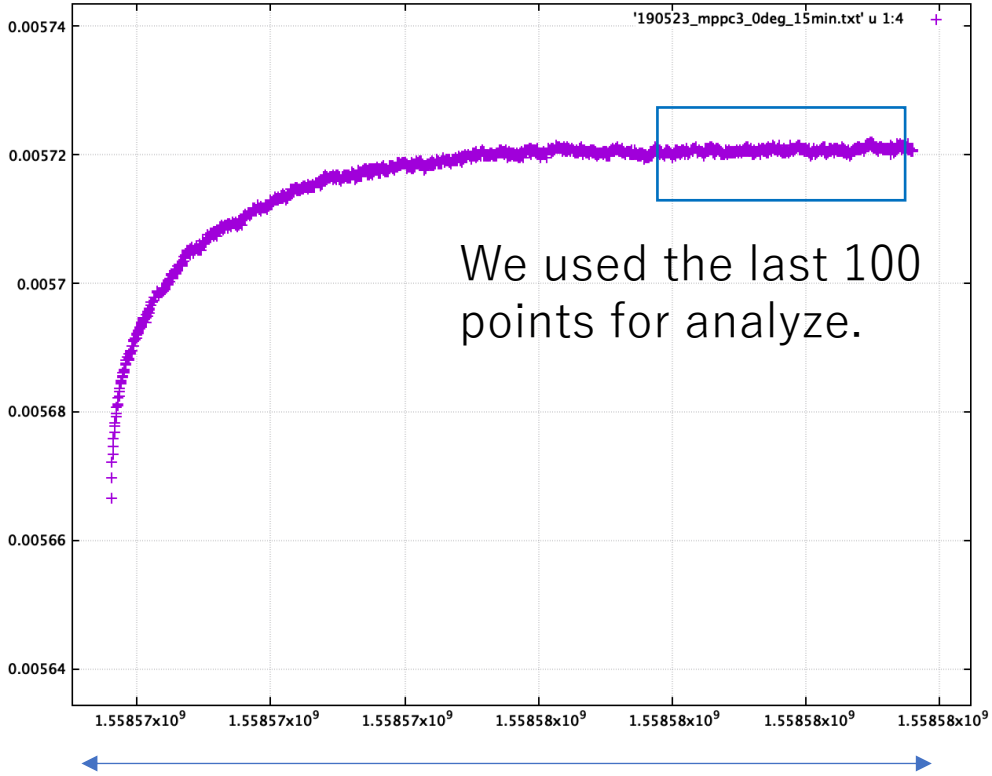
Backup

IV measurement for Pre/Post-irradiated S14160



IV curve of after 5krad irradiation 。(@ 0 °C)



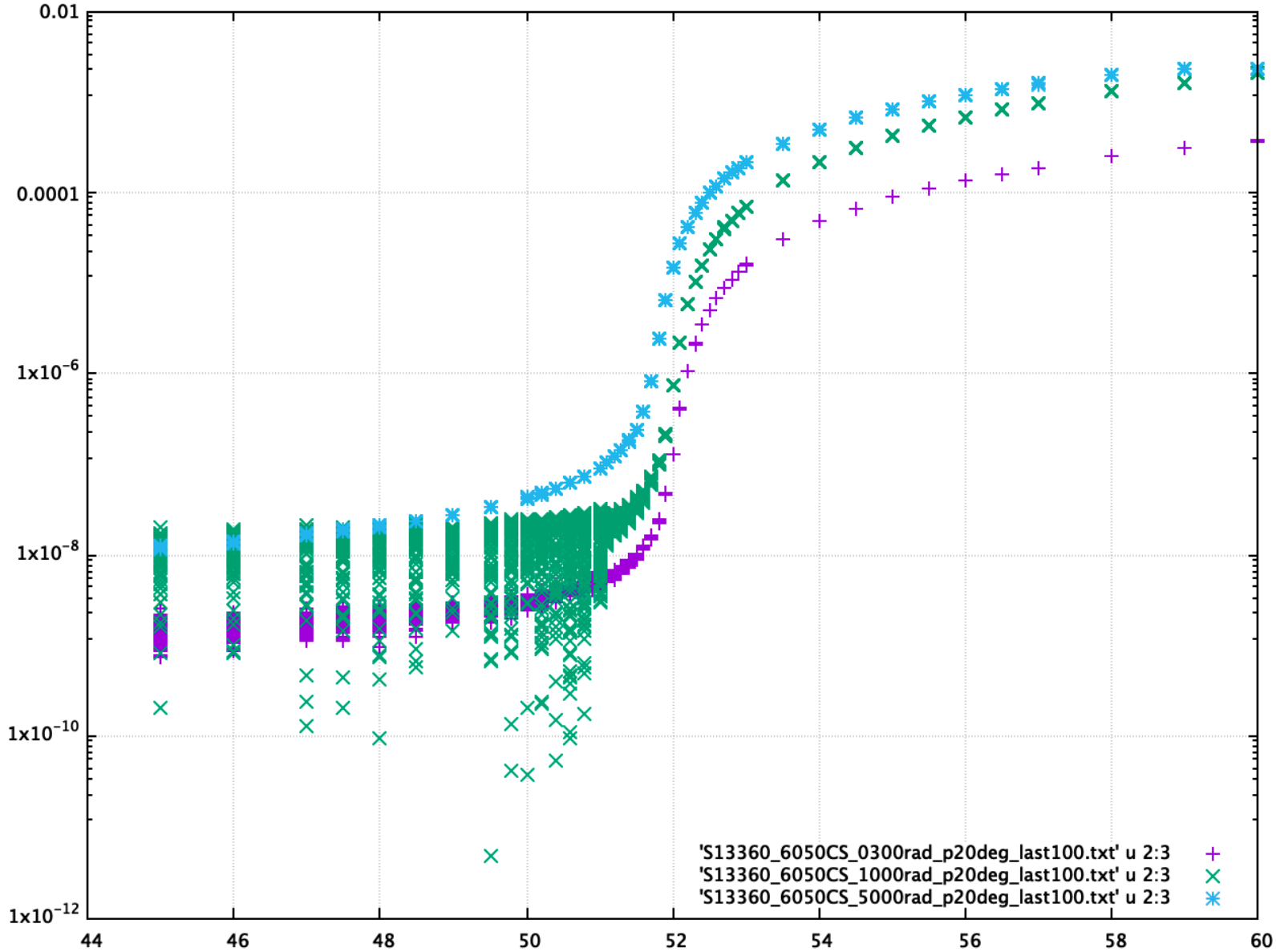


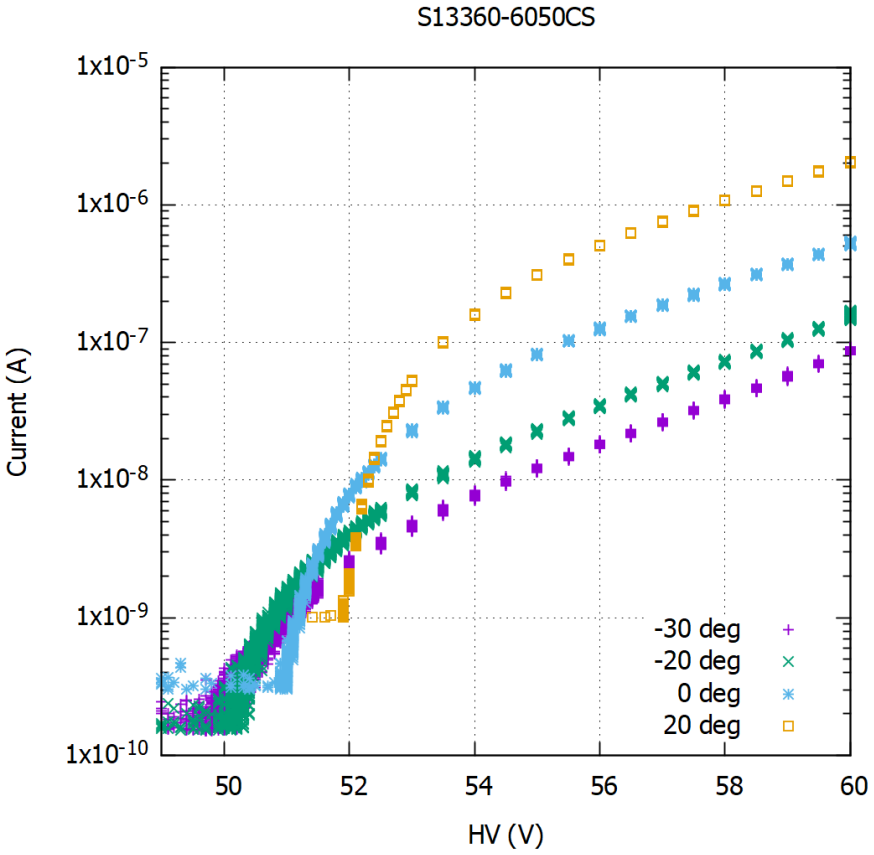
Dark current increases about
15 min after we applied voltage.

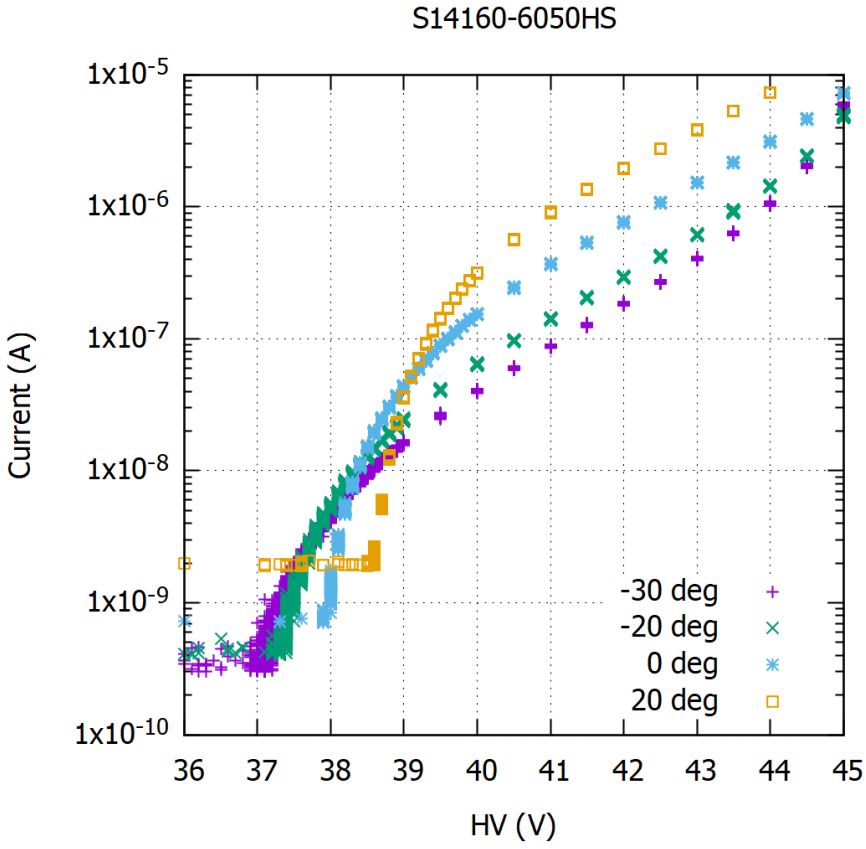
- SiPM temperature increases with the increasing of dark current?
- Charge up to some capacitors in readout circuit?

We did not take this effect into account for S13360 last year.

アニーリング？後のIV曲線




S13360-6050CS
Current (A)
1x10-5
1x10-6
1x10-7
1x10-8
1x10-9
1x10-10
50
52
54
56
58
60
HV (V)
-30 deg
-20 deg
0 deg
20 deg

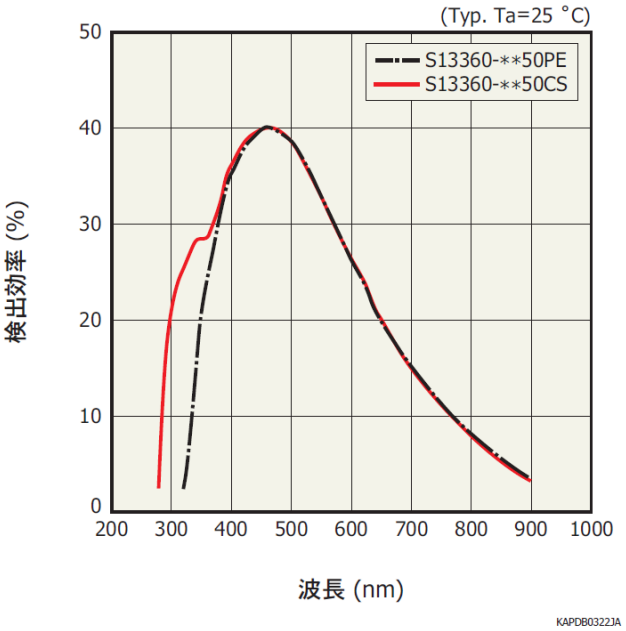

S14160-6050HS
Current (A)
1x10-5
1x10-6
1x10-7
1x10-8
1x10-9
1x10-10
36
37
38
39
40
41
42
43
44
45
HV (V)
-30 deg
-20 deg
0 deg
20 deg

電気的および光学的特性 (指定のない場合はTyp. Ta=25 °C)

型名	測定条件	感度波長範囲 λ (nm)	最大感度波長 λp (nm)	検出効率 PDE*4 λ=λp (%)	ダークカウント*5 Typ. (kcps)	ダークカウント*5 Max. (kcps)	端子間容量 Ct (pF)	増倍率 M	降伏電圧 VBR (V)	クロストーク確率 (%)	推奨動作電圧 Vop (V)	推奨動作電圧の温度係数 ΔTVop (mV/°C)
S13360-1325CS	Vover =5 V	270 ～ 900	450	25	70	210	60	7.0 × 10^5	53 ± 5	1	VBR + 5	54
S13360-1325PE		320 ～ 900										
S13360-3025CS		270 ～ 900			400	1200	320					
S13360-3025PE		320 ～ 900										
S13360-6025CS		270 ～ 900			1600	5000	1280					
S13360-6025PE		320 ～ 900										
S13360-1350CS	Vover =3 V	270 ～ 900		40	90	270	60	1.7 × 10^6		3	VBR + 3	
S13360-1350PE		320 ～ 900										
S13360-3050CS		270 ～ 900			500	1500	320					
S13360-3050PE		320 ～ 900										
S13360-6050CS		270 ～ 900			2000	6000	1280					
S13360-6050PE		320 ～ 900										
S13360-1375CS	Vover =3 V	270 ～ 900		50	90	270	60	4.0 × 10^6		7	VBR + 3	
S13360-1375PE		320 ～ 900										
S13360-3075CS		270 ～ 900			500	1500	320					
S13360-3075PE		320 ～ 900										
S13360-6075CS		270 ～ 900			2000	6000	1280					
S13360-6075PE		320 ～ 900										

*4: 検出効率は、クロストークとアフターパルスを含んでいません。
*5: 閾値=0.5 p.e.
注) 上記の特性値は、表中の増倍率が得られる動作電圧における値です (製品に添付されるデータを参照してください)。

ピクセルピッチ: 50 µm



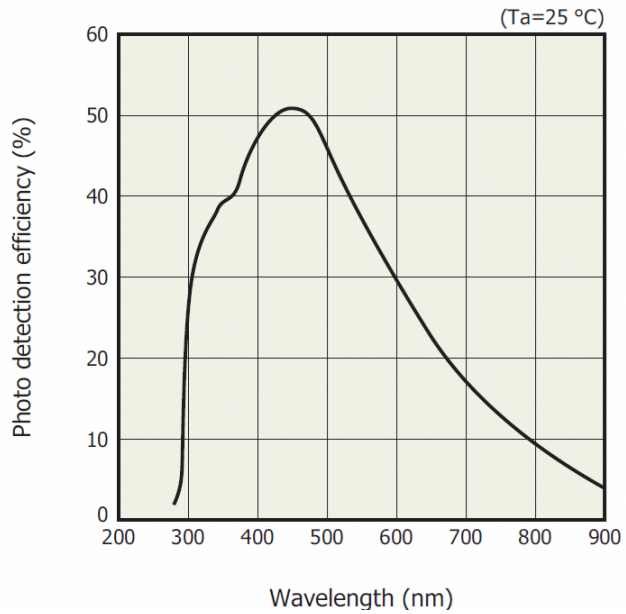
KAPDB0322JA

Electrical and optical characteristics (Typ. Ta=25 °C, overvoltage=2.7 V, unless otherwise noted)

Parameter		Symbol	S14160/S14161 -3050HS-04, -08	S14160/S14161 -4050HS-06	S14160/S14161 -6050HS-04	unit
Spectral response range		λ	270 to 900			nm
Peak sensitivity wavelength		λp	450			nm
Photon detection efficiency at λp*3		PDE	50			%
Breakdown voltage		VBR	38			V
Recommended operating voltage*4		Vop	VBR + 2.7			V
Vop variation among channels in one array*5	Typ.		±0.05			V
	Max.		±0.1			
Dark current	Typ.		0.6	1.1	2.5	µA
	Max.		1.8	3.3	7.5	
Crosstalk probability		-	7			%
Terminal capacitance		Ct	500	900	2000	pF
Gain		M	2.5 × 10^6			-
Temperature coefficient of recommended reverse voltage		ΔTVop	34			mV/°C

*3: Photon detection efficiency does not include crosstalk and afterpulses.
*4: Refer to the data attached for each product.
*5: The parameter is for the S14161 series (multichannel type)

Photon detection efficiency vs. wavelength (typi



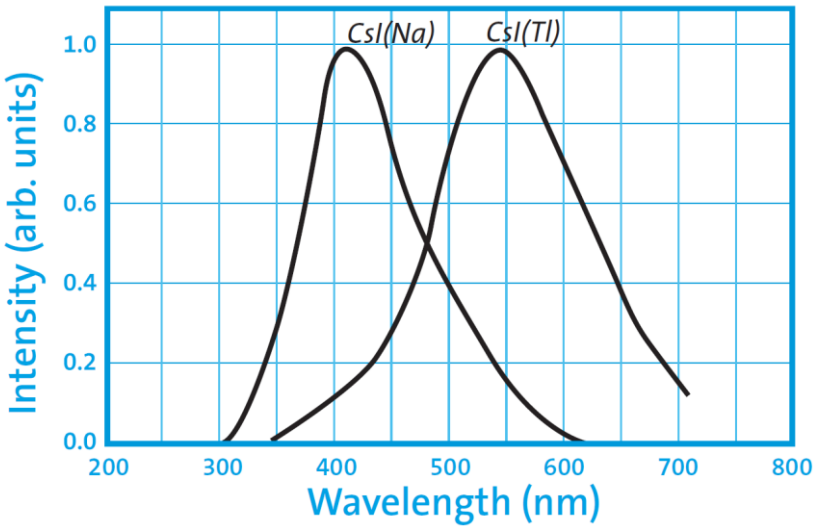
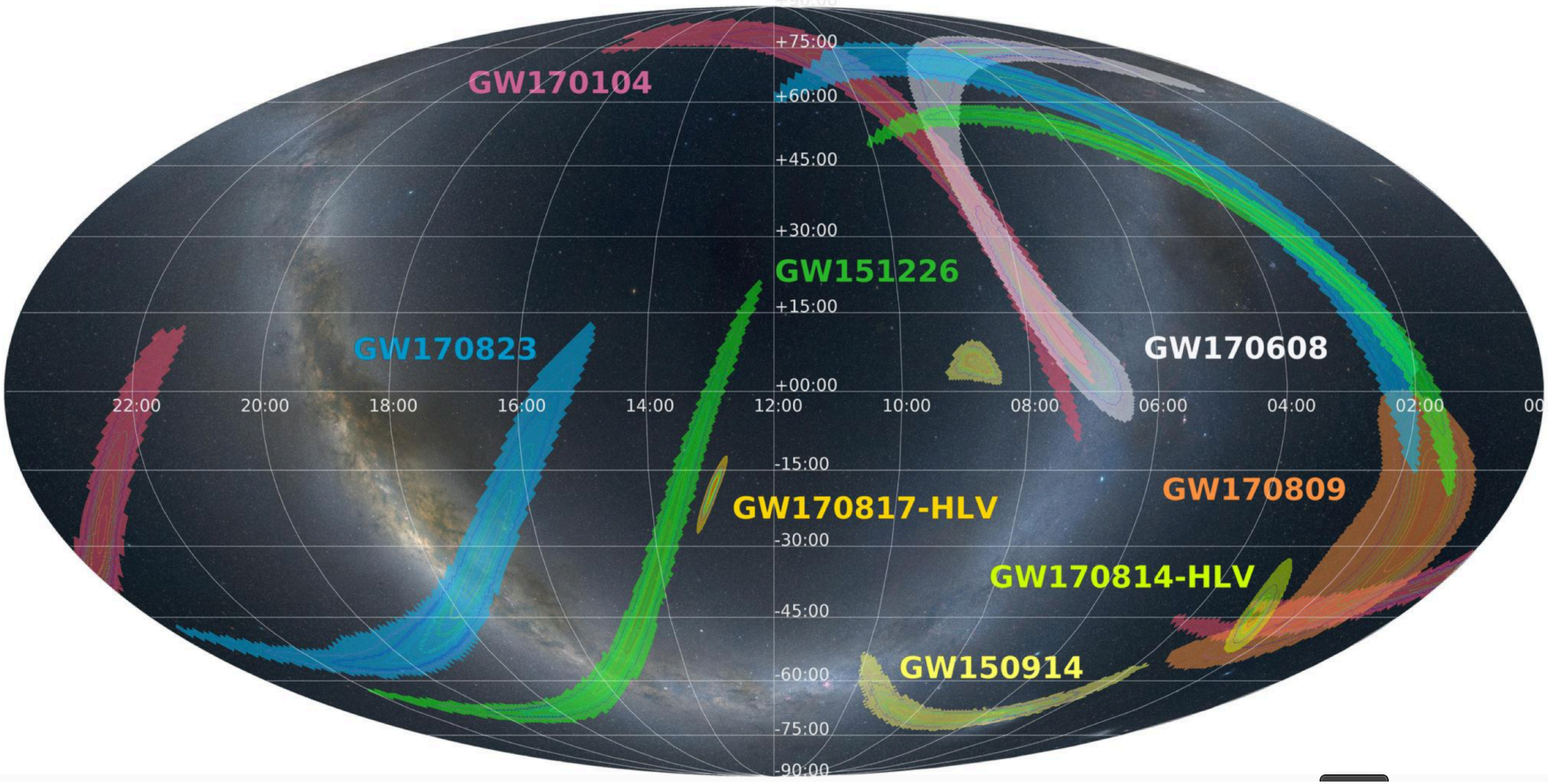


Figure 1. Scintillation emission spectrum of CsI

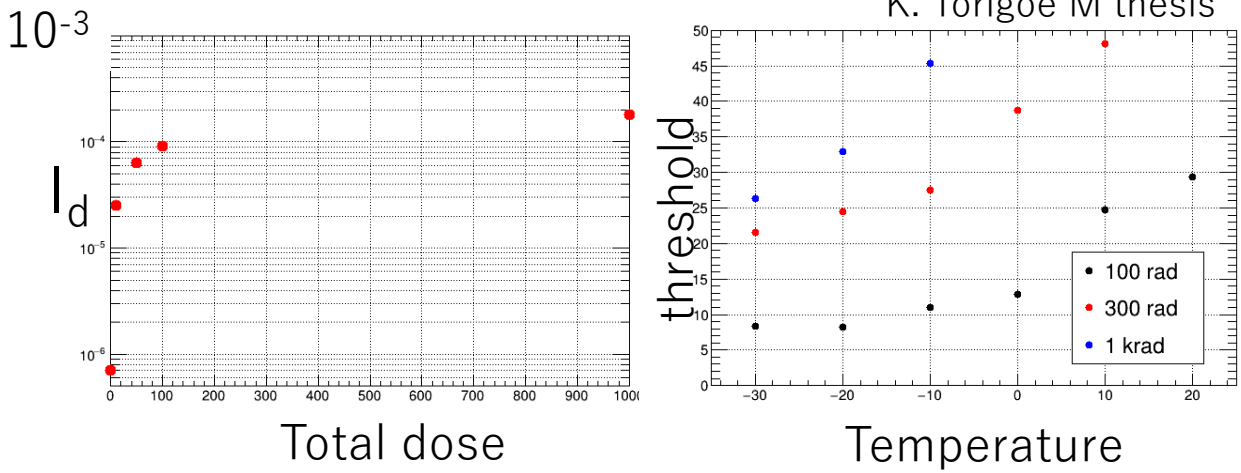

GW170104
GW151226
GW170823
GW170608
GW170817-HLV
GW170809
GW170814-HLV
GW150914
+75:00
+60:00
+45:00
+30:00
+15:00
+00:00
-15:00
-30:00
-45:00
-60:00
-75:00
-90:00
22:00
20:00
18:00
16:00
14:00
12:00
10:00
08:00
06:00
04:00
02:00

Right After Irradiation (last/this year)

S13360-6050CS→Proton irradiation test in Nov. 2018

K. Torigoe M thesis

Bias : 55V constant
Total dose increase
→I_d increased
→threshold get worse



Dark current and threshold for S13360-6050CS right after irradiation

Stored in room temp about 7 months and measured.
→**Somehow recovered?**

S14160-6050HS→Proton irradiation test in Mar. 2019

→energy threshold and dark current get worth with the proton irradiation. I_d ~ mA

S13360(~7 months after irr.) vs S14160(right after irr.)
Which SiPM is suit for CAMELOT mission?

1krad = 10 J(6.242e+19eV)/1kg
In case of proton with the energy of 200MeV,
1kgあたり、6.242e+19eV/200e+6eV ~ 3e+11 protons
3e+11 1MeV n_eq/kg??

MPPC: S13360-6050cs → 0.6*0.6*0.13 cm^3
Si密度：2.3290g/cm^3 * 0.6*0.6*0.13 cm^3 ~ 0.1g
なので、
3e+6 1MeV n_eq/MPPC ??