In-orbit degradation of Hamamatsu MPPCs (SiPMs)

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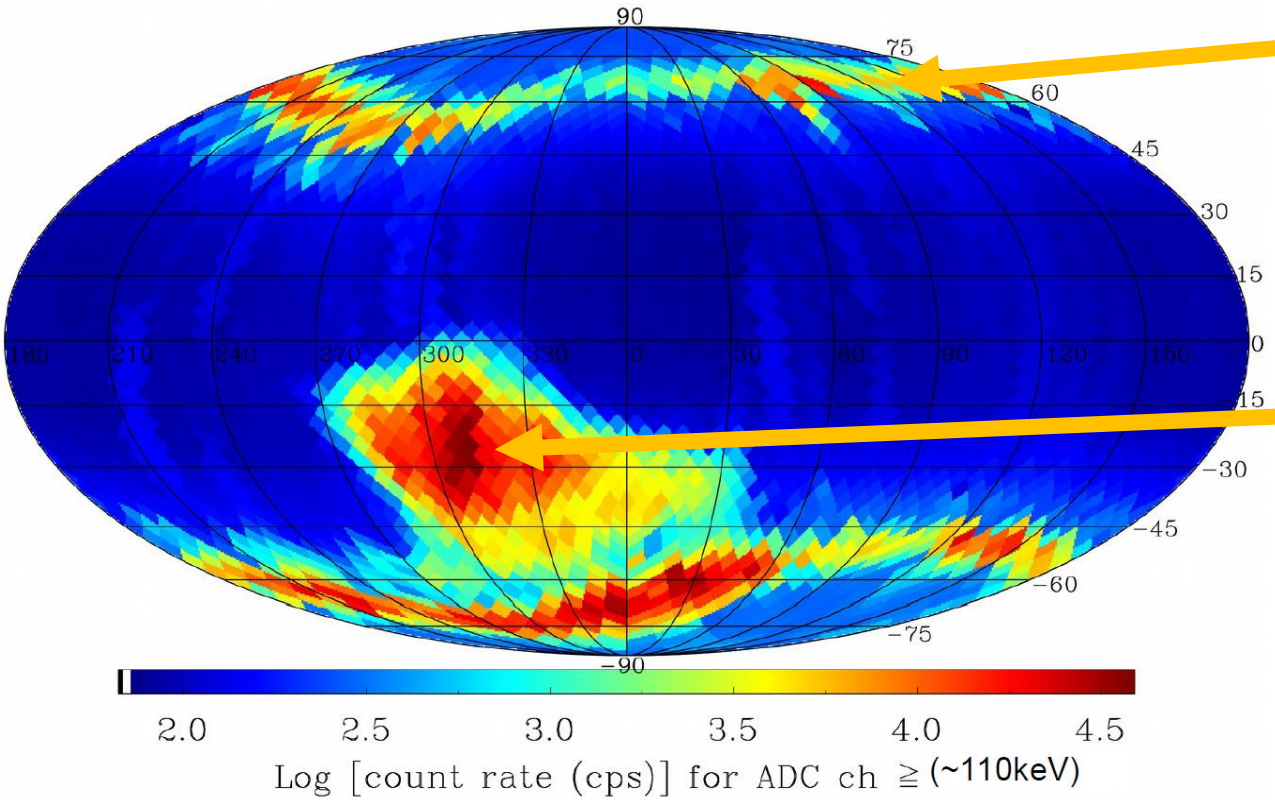
https://doi.org/10.1016/j.nima.2020.164945
https://doi.org/10.1016/j.nima.2020.164673

Background map by GRBAlpha (J. Ripa)



Electrons@Poles
Can be shielded.

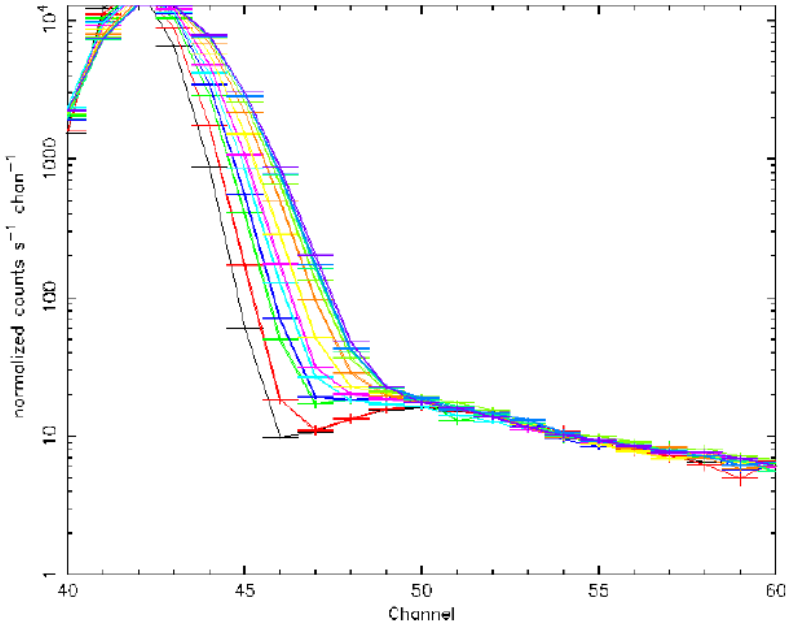
Protons@SAA
Penetrating =>
Can**not** be shielded.
Damaging…

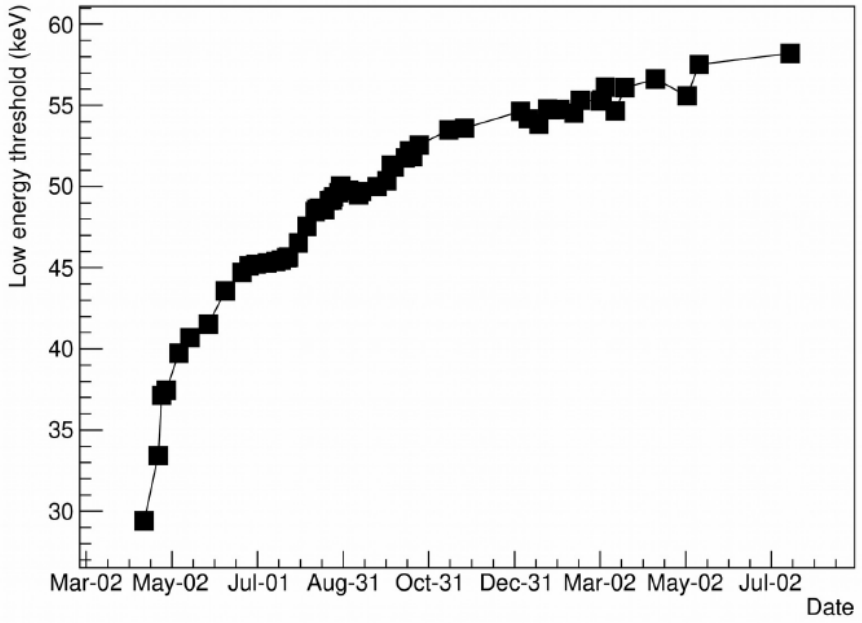
SiPM (MPPC) performances are degrading in orbit

J. Ripa

GRBALPHA: DEGRADATION OF MPPC IN SPACE

- Increasing of dark current (noise) due to the radiation damage of MPPCs by the trapped protons
- Noise peak becomes wider and the low-energy threshold increases
- Expected from the ground beam experiment
- Before launch the low-energy threshold was ~10 keV
- 15 months after the launch it was ~58 keV
- After one year on orbit the degradation remains at acceptable level

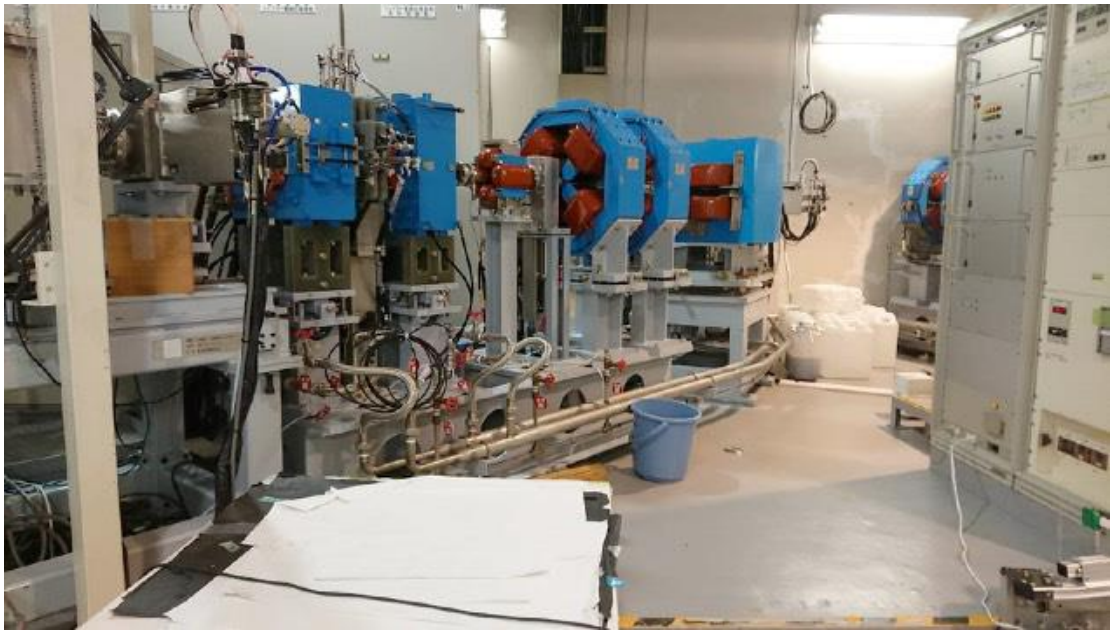


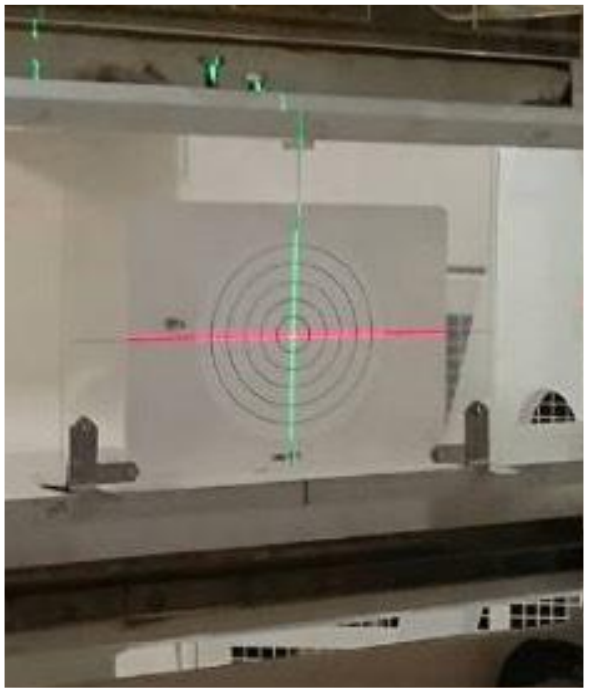


Experimental Setup of Proton Irradiation

Experiments at **Wakasa-wan energy research center** (Japan)
200 MeV protons
1000 rad = 10 Gy corresponds to 1.71 x 10^{10} protons/cm2
(6 x 10^{9} 1 MeV n_{eq})

We are assuming 1000 rad /year without shields (@~550 km).
several 100 rad /year with 1-mm Pb shield.



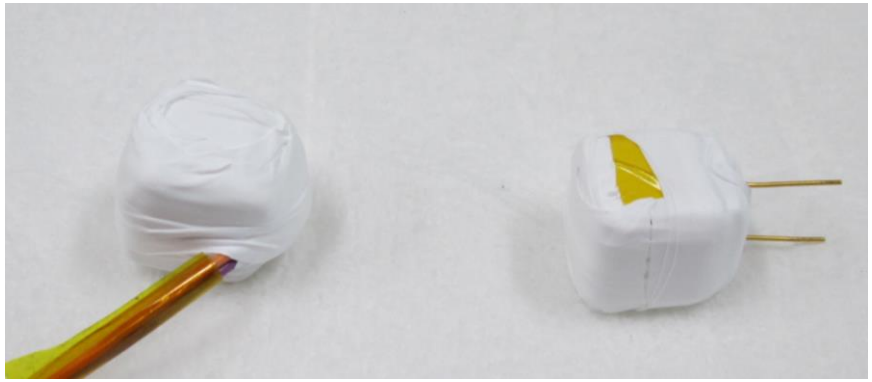


2 MPPC Series

Only MPPCs are irradiated.

with 1 cm^3 CsI (Tl) for energy spectra

Both have 6x6 mm^2 size
left … S13360-6050CS
right … S14160-6050HS

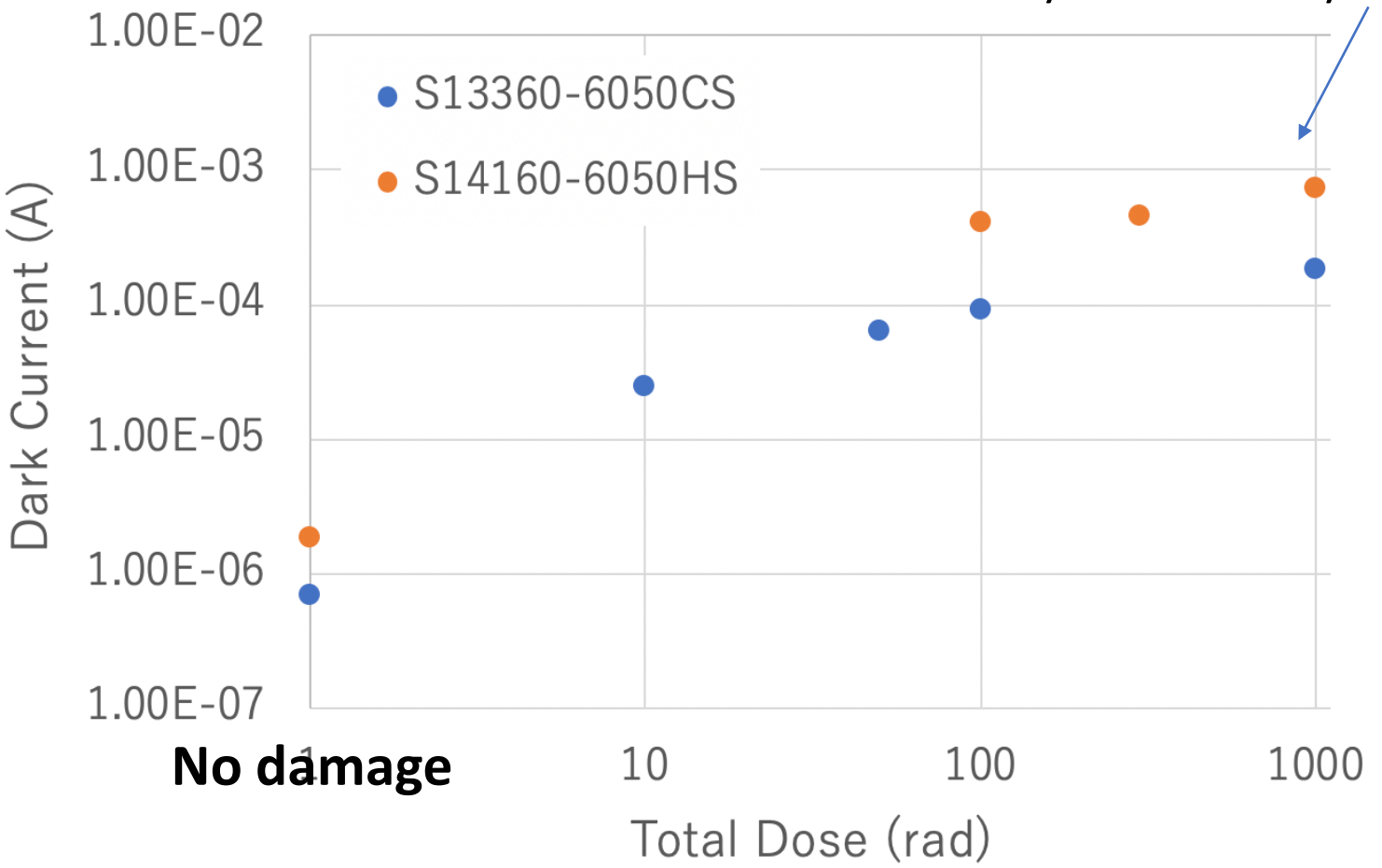


S14160 has
- High PDE
- High gain
- Low operation voltage
- (but high dark current)

	PDE (%)	Gain (10^6)	Dark current (uA)	Operation voltage (V)
S13360-6050CS	40	1.7	0.388	54.4
S14160-6050HS	50	2.5	1.63	41.0

Dark current (same Vop @room temperature)

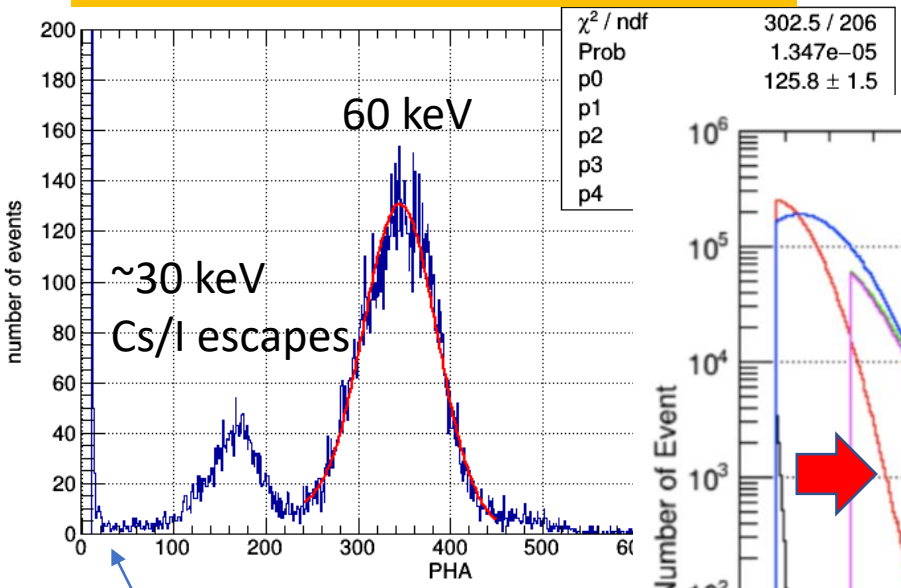
With 1 kΩ resister, the actual voltage is effectively decreased by ~1V.



Only 10 rad causes significant damage (increases >x10 times).
Both series show the similar trend.

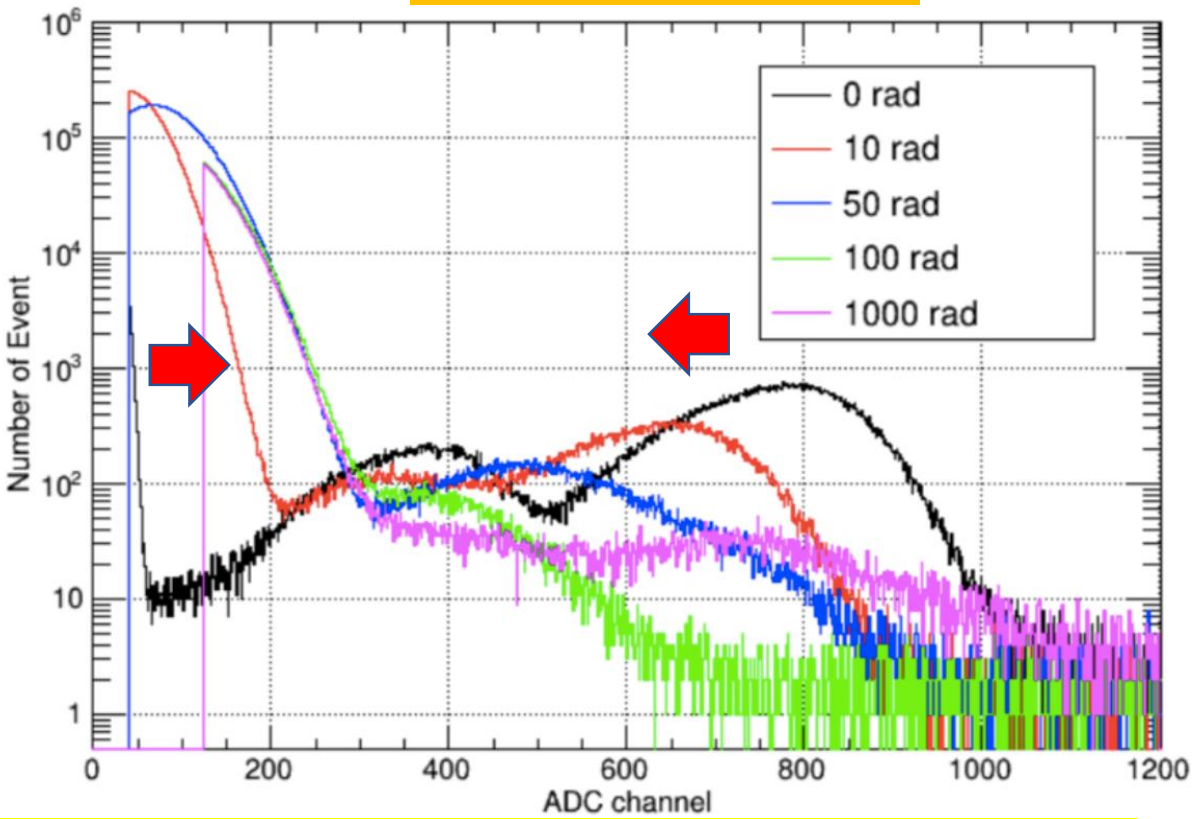
Energy spectra (same Vop @room temperature)

^{241}Am with CsI (Tl) (no damage)



Noise threshold: a few keV

With proton damage

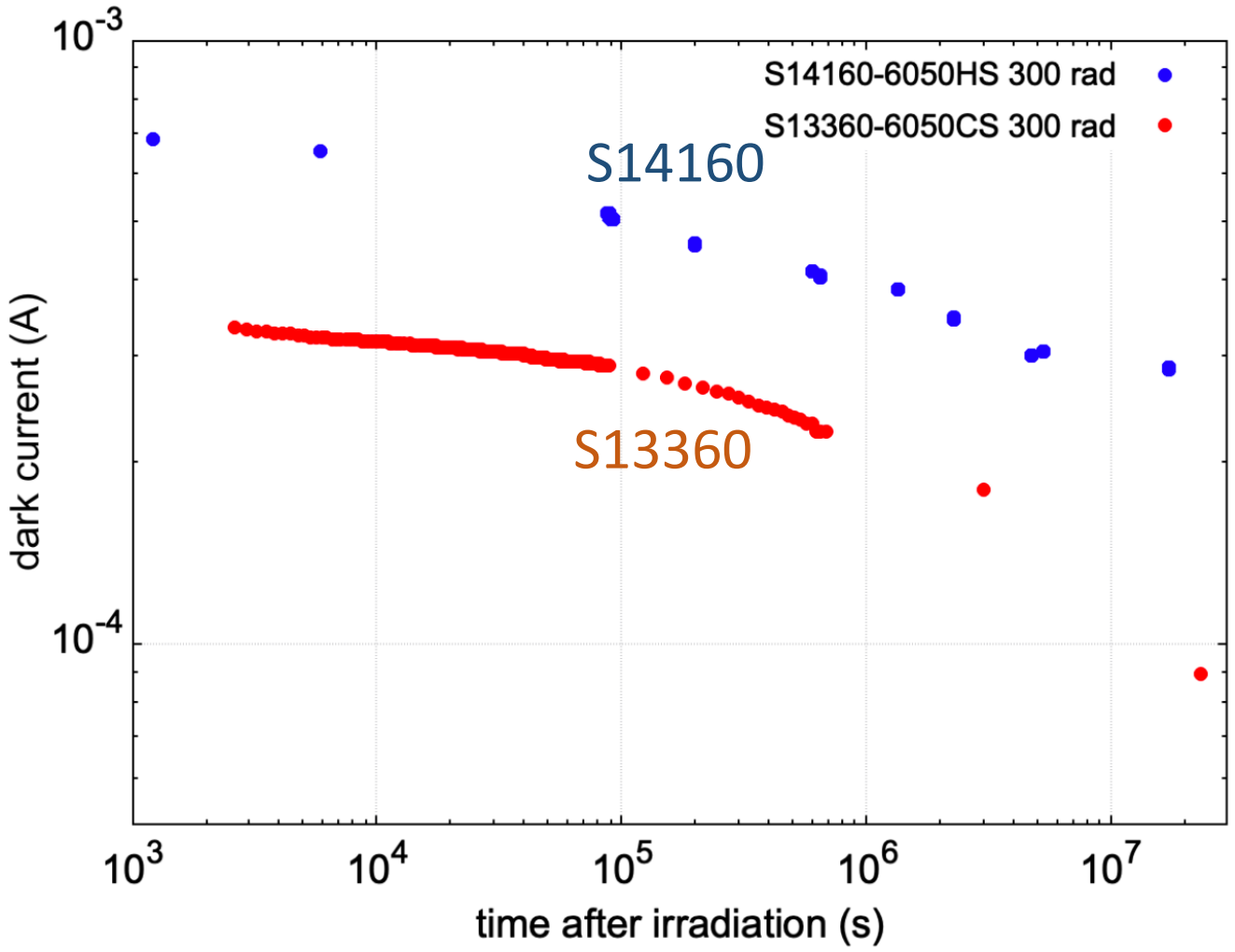


Even with 10 rad irradiation, noise threshold increases significantly.
(Gain decreases with the effective voltage decrease.)
With 1000 rad, 60 keV peak is hard to see.

Any recovery of SiPM (MPPC) performance?

- Annealing
- Cooling (lower temperature)

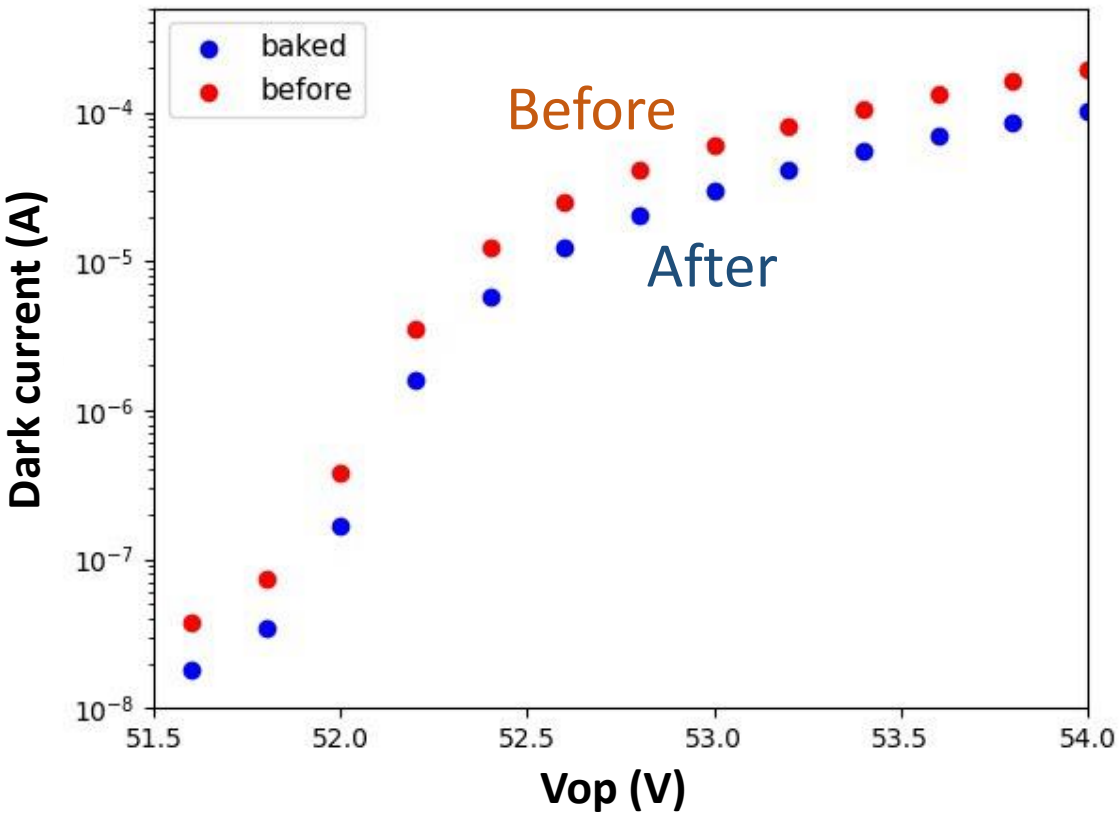
Annealing@room temperature: Dark current



The dark current decreased by 2-3 times over ~half a year.
Both series show the similar trend.

Annealing@+150℃, 3 hours : Dark current

S13360-6050CS (1000 rad)@+20℃

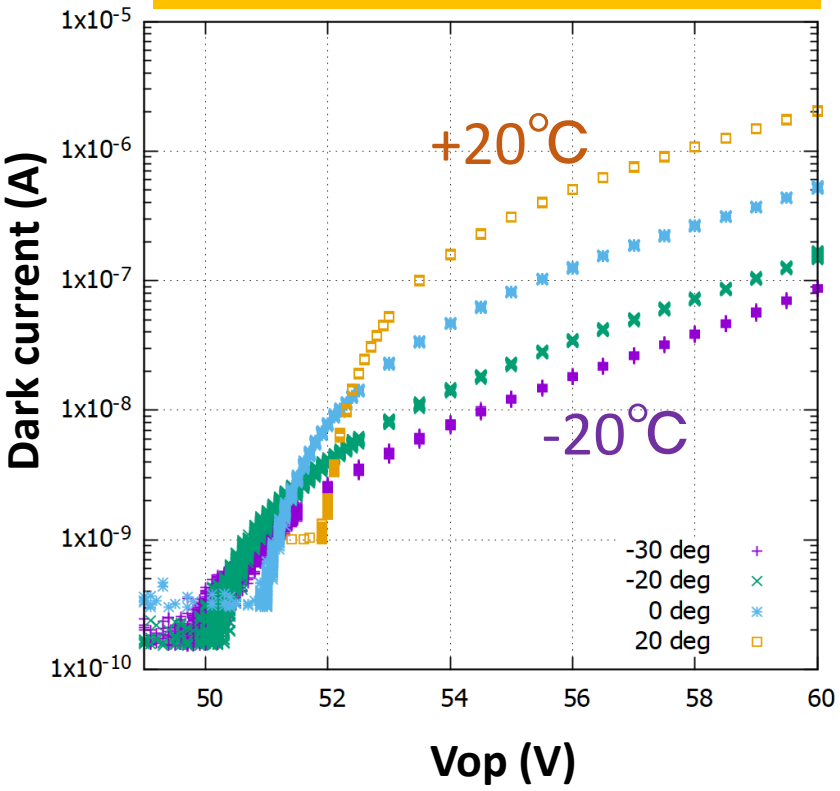


The dark current decreased by ~2 times at hot environment.
=> Annealing does not recover to the original performance.

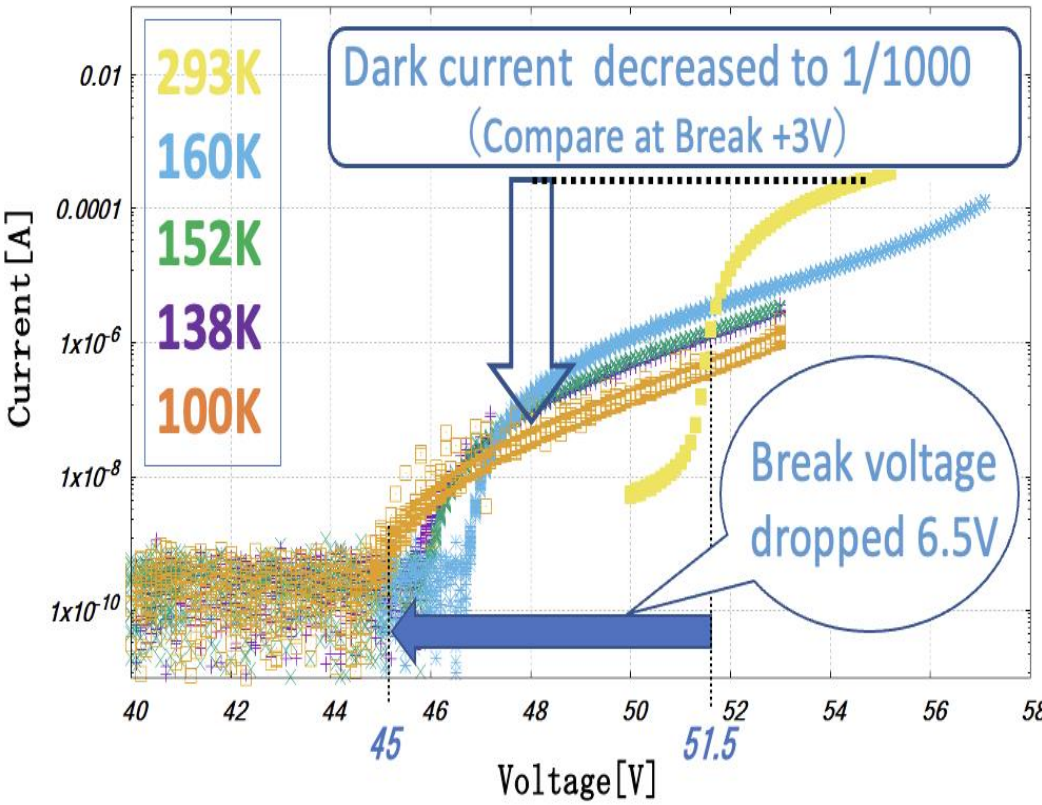
Lower temperature to reduce dark current

Niwa's poster

S13360-6050CS (**no damage**)



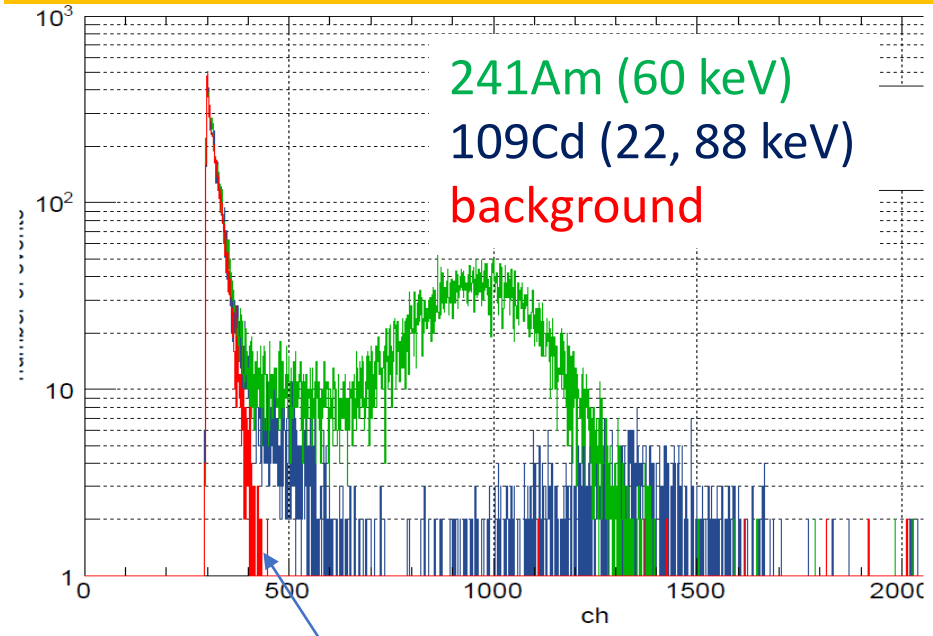
S13360-6050VE (**1000 rad**)



Even damaged MPPCs reduces dark current at lower temperature.
=> (If possible) lower environment is better in orbit.

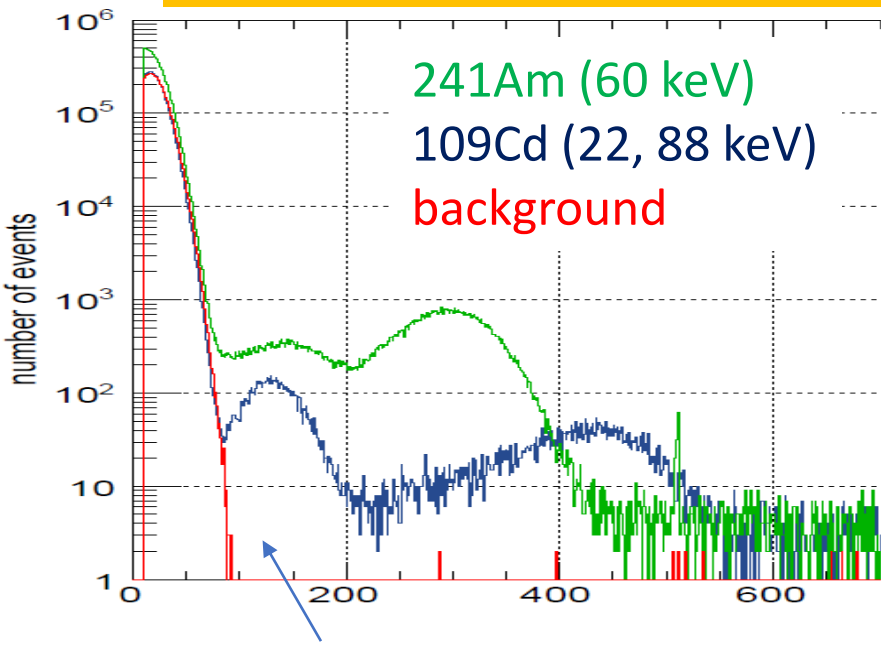
Energy spectra (S13360, 1000rad)@different dark current

Just after the irradiation@-30 degC



22 keV is not easy to see…

7 months later@-30 degC

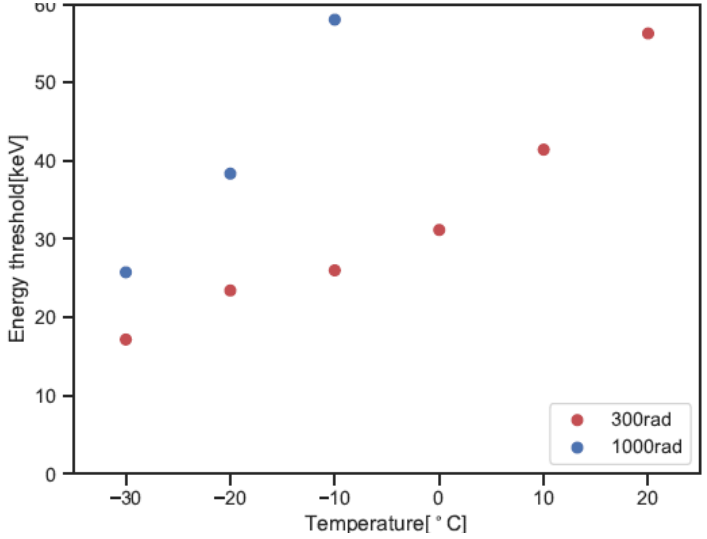


22 keV is easy to detect.

Lower dark current is important to achieve the lower threshold.

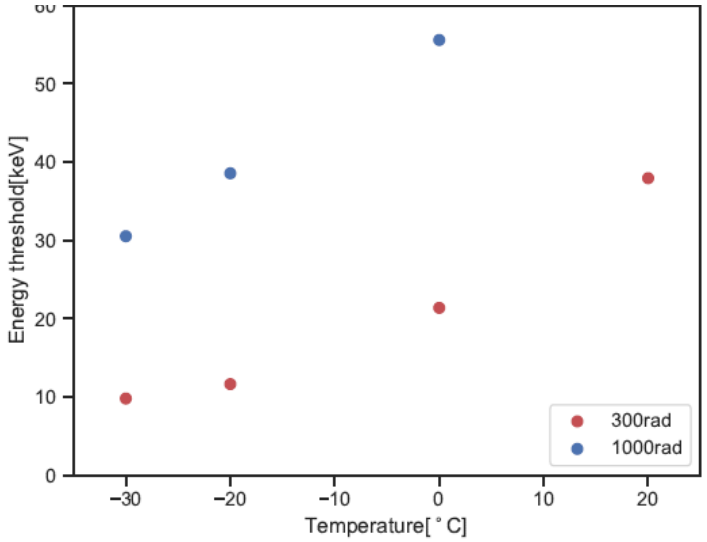
Energy threshold (S13360)

Just after the irradiation at suggested Vop

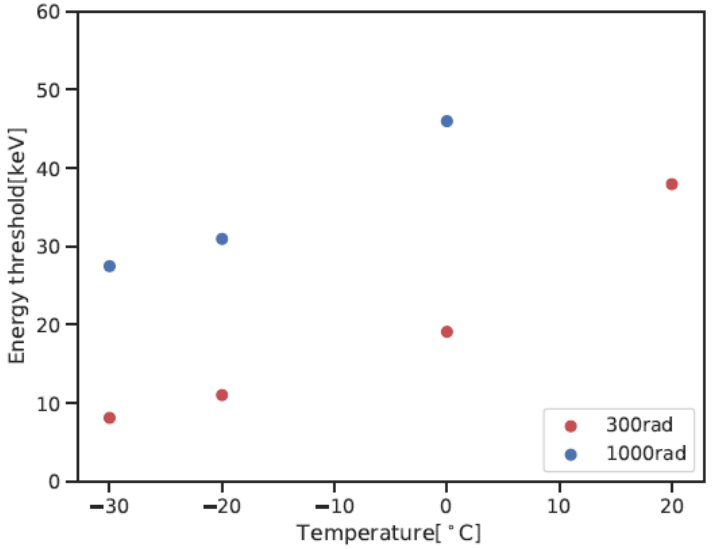


(in black case
=> x1.7 better threshold
with surface mount)

7 months later at suggested Vop



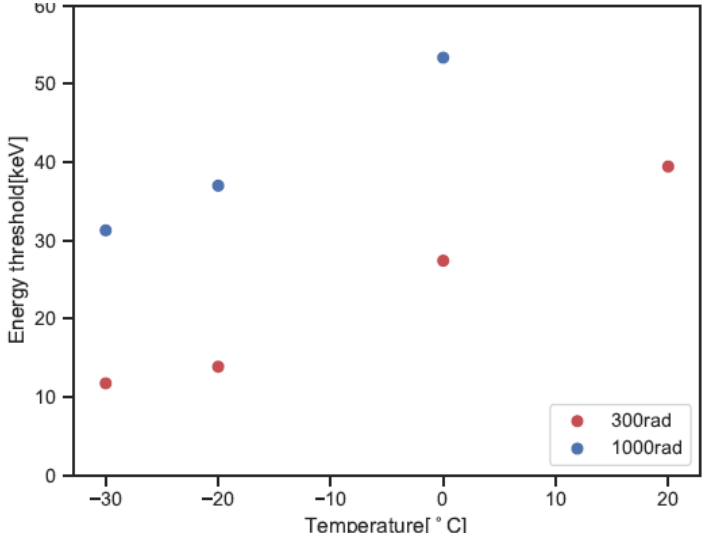
7 months later at best Vop



Typically, lower Vop is better to reduce too much dark currents.

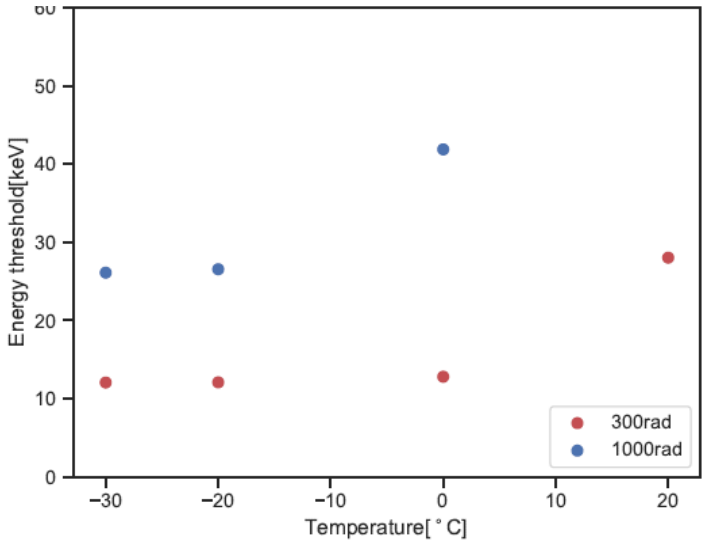
Energy threshold (S14160)

Just after the irradiation at suggested Vop

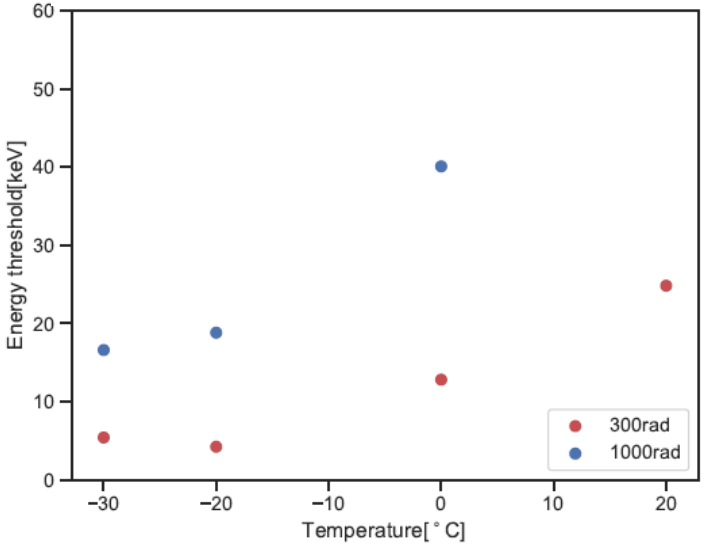


Comparable thresholds for both MPPCs with surface mounting.

7 months later at suggested Vop



7 months later at best Vop



Typically, lower Vop is better to reduce too much dark currents.

Summary & Suggestions

- MPPC dark current significantly increases with radiation damage.
- It is important to reduce the dark current to keep lower threshold.

- **Annealing:** recover by a factor of several (although not dramatically).
- **Cooling**: it can be ok for large satellites. Niwa's poster
  For CubeSats, it can be difficult…

- **MPPC size:** should be just enough to correct scintillation photons,
  while not too large (for less dark current).
- **Lower altitude**: ISS (400 km) has ~1/10 less SAA protons than 550 km.
- **Shielding** (for electrons): One side is already ok with scintillators.
  The other side needs Pb etc. (even with a thin layer)
- **Scintillators**: Higher light yield, Faster decay
- **Timing coincidence**: Morishita's poster
- Other **photodetectors**: **CMOS** for Kayanoki's poster