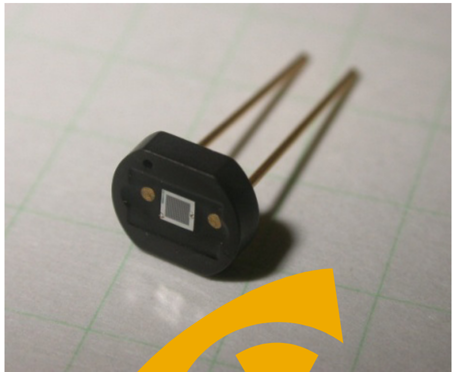
Effects of Radiation Damage on Multi-Pixel Photon Counter (MPPC)



National Defense Academy in Japan

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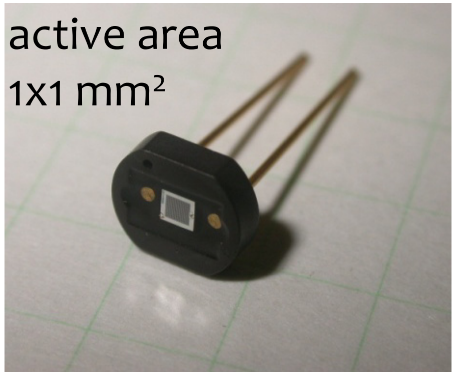
on behalf of **the KEK Detector Technology Project (KEK-DTP)**

The 2008 IEEE Nuclear Science Symposium
@ Dresden, Germany
21 Octorber 2008

Features of MPPC

MPPC ... High-sensitivity photon detector
developed by Hamamatsu Photonics



MPPC (400 pixel type)

Operation principal

- Array of Geiger-mode APD pixels
- Summing charge signals from all pixels
  → Analog pulses responsive to the intensity of light

Gain ~ 10^6 (photon counting is possible)

Comparison with PMTs

disadvantages:
- small active area (1x1 ~ 3x3 mm^2)
- narrow dynamic range
- temperature dependence (Gain, P.D.E.)

advantage :
- compactness
- low voltage (~70 V)
- insensitivity to magnetic field
- low cost capability

MPPC is a suitable device for
- **Scintillating / WLS fibers readout (HEP experiments)**
- **Fine segmented crystals readout (PET applications)**

Radiation Hardness Studies @ KEK-DTP

For practical use of the MPPC,
radiation hardness is an issue to be made clear.

Experimental program at KEK-DTP

- **γ-ray (^{60}Co)**
- **protons**
- **reactor neutrons**
- **heavy ions (C^{6+})**

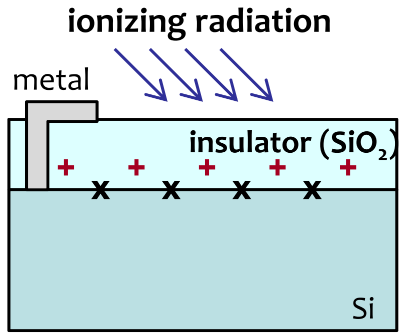
--- Contents of this talk ---

- Summary of the effects caused by radiation damage
- What we can do to improve radiation hardness
- Introduction our present work to improve radiation hardness of MPPC

Radiation Damage on Semiconductor Devices

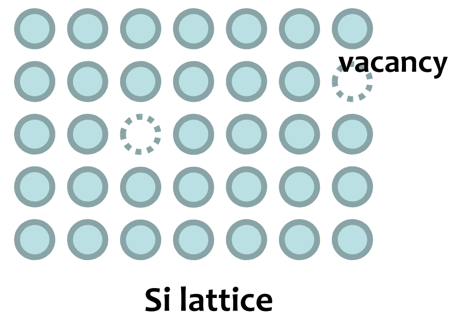
- **Ionization process**
  - electric property change due to **positive charge trapping in an insulator** (temporary effect)
  - increase of trapping centers **at Si-Insulator interface**

  γ-rays, electrons, other ionizing radiation



- **Non-ionization process (NIEL)**
  - increase of trapping centers in the Si bulk
    due to **lattice defects** caused by scattering off Si nuclei

  neutrons, protons, other heavy particles

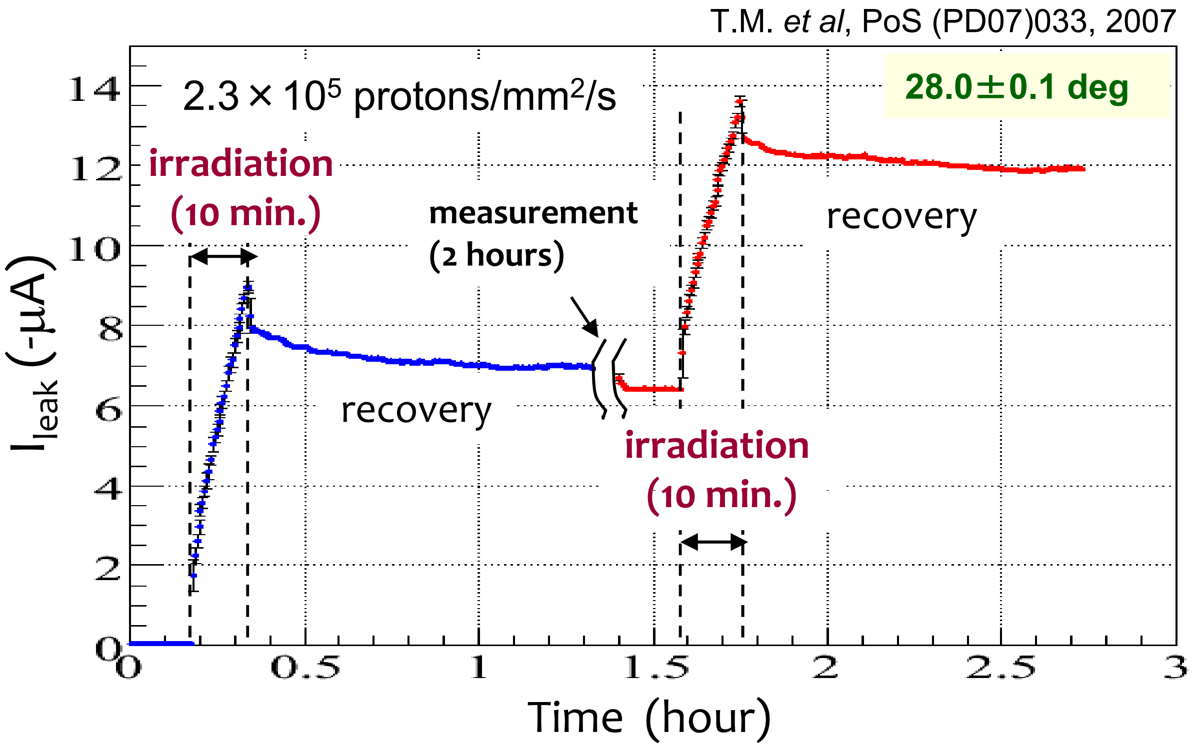


Formation of new centers in the Si band gap
raises thermal carrier generation

→ increase of leakage current (I_{leak})

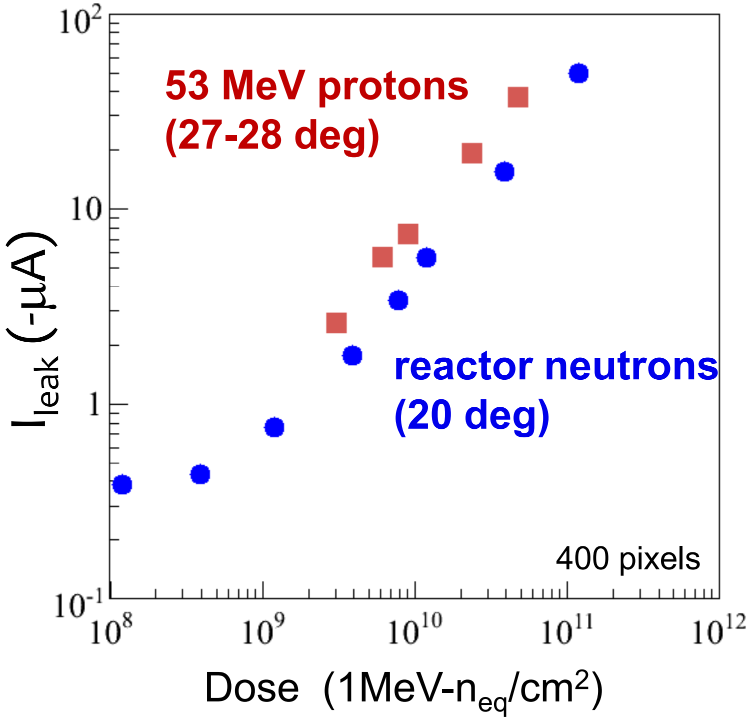
Proton/Neutron Irradiation (1)

Time variation of I_{leak} (53 MeV protons)



I_{leak} v.s. Dose (V_{over} = 1.6 V)

($V_{over} = V_{bias} - V_{breakdown}$)



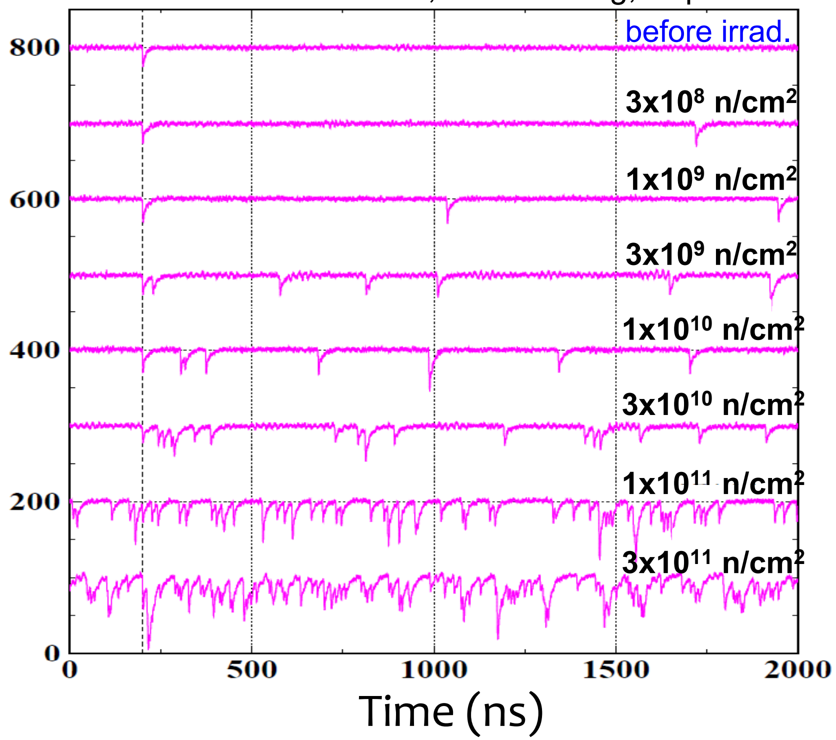
- Leakage current linearly increased with dose.
- Recovery effects were seen, but not completely recovered to the original condition.

- Similar tendency for both proton and neutron irradiation
  - ✓ The factor ~2 difference would become less significant if temp. difference is considered.

Proton/Neutron Irradiation (2)

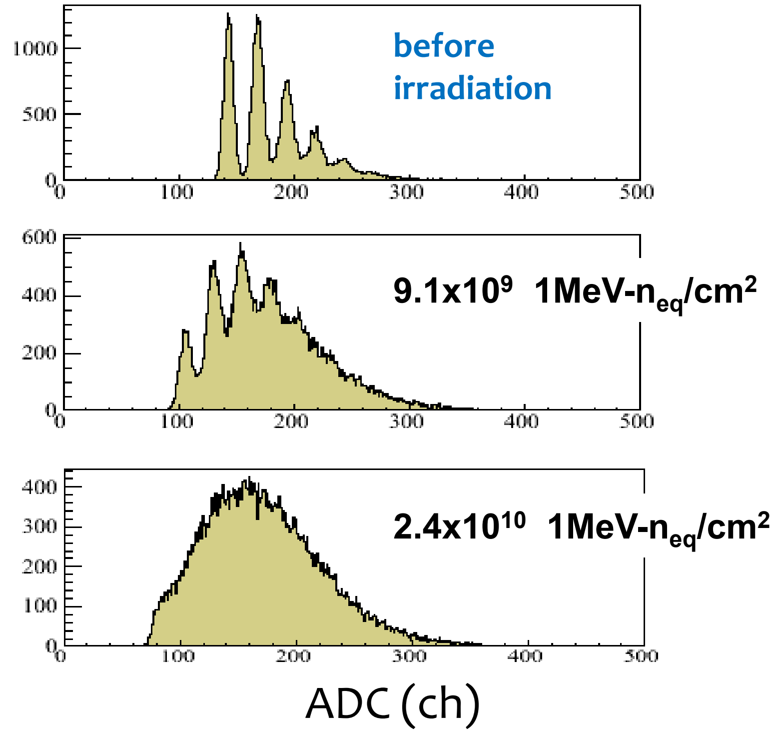
Typical waveform of dark pulses (after neutron irradiation)

I.Nakamura, JPS meeting, Sep. 2008



ADC distributions (proton irrad.)

T.M. *et al*, PoS (PD07)033, 2007



lost of photon counting capability

due to baseline fluctuation and noise pile-up

$\sim 10^{10}$ 1MeV-n_{eq}/cm^2

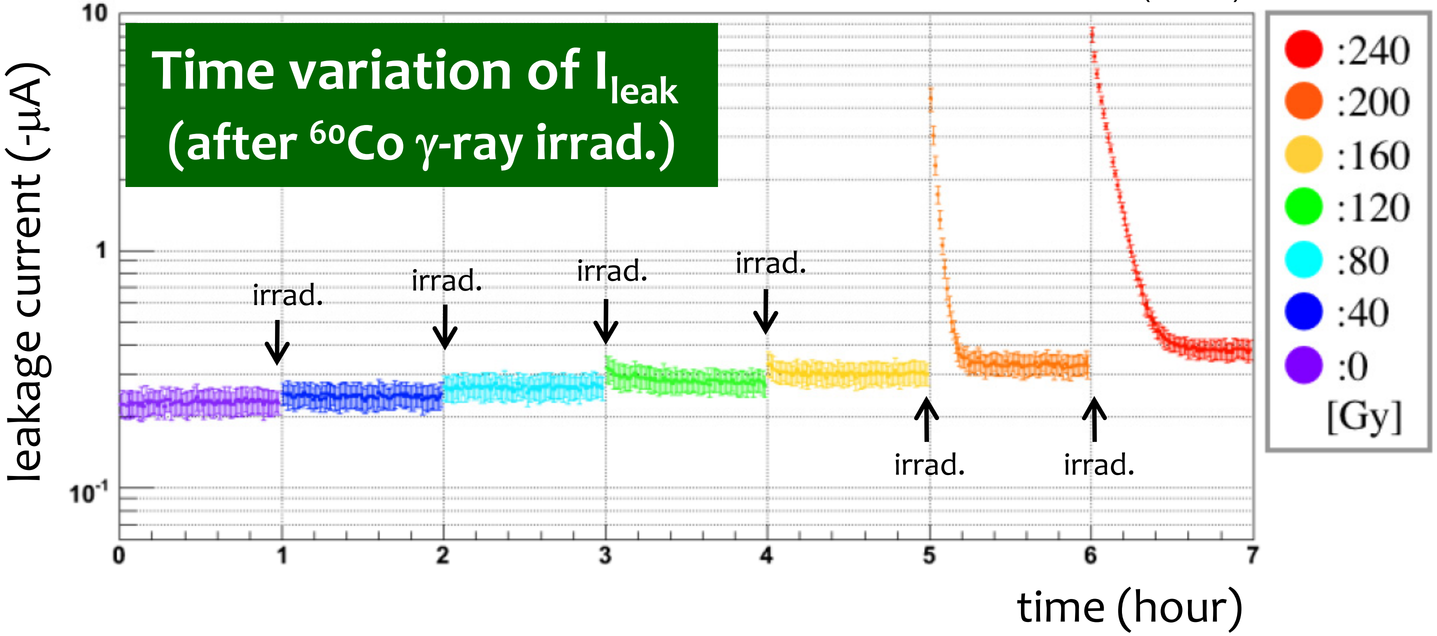
in both cases of the proton/neutron irrad.

Damage effects caused by proton and by neutron irradiation are almost scaled by NIEL.

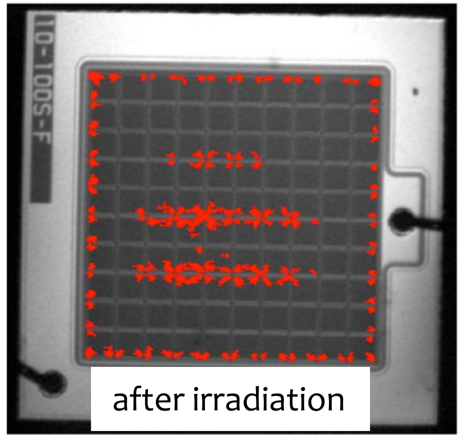
→ **Bulk damage is dominating for the proton irradiation**

γ-ray Irradiation

T.Matsubara *et al*, PoS (PD07)032, 2007

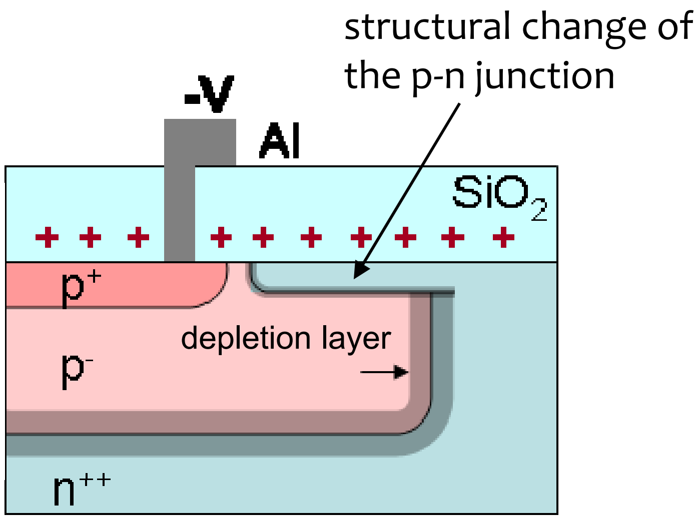


I.R. camera view



observation of hot spots and high dark pulses (~10p.e.)

A qualitative interpretation



local drop in the breakdown voltage at around pixel edges

Effects of the electric property change is significant for the γ-ray irradiation.

Toward radiation-resistant MPPC...

- **protons / neutrons**

bulk damage caused by lattice defects is dominating.

➡ **inactivate the lattice defects**

(ex.) doping O-atoms to Si bulk （DOFZ technology）

G.Lindstrom, NIM A512(2003)30

- **γ-ray (^{60}Co)**

electrical property change due to trapped charge near the Si-insulator interface is important.

➡ **prevent the build-up of the trapped charge**

(ex.) change material and/or thickness of the insulator

First step : study of radiation-resistant device **against γ-rays**
(more accessible to the manufacturer)
Next step : ... against protons/neutrons

Our present work

Collaboration with Hamamatsu Photonics

To improve radiation hardness of MPPC **against γ-rays**,
special samples with DIFFERENT STRUCTURE have been provided.

↳ **γ-ray irradiation**
(our present work)

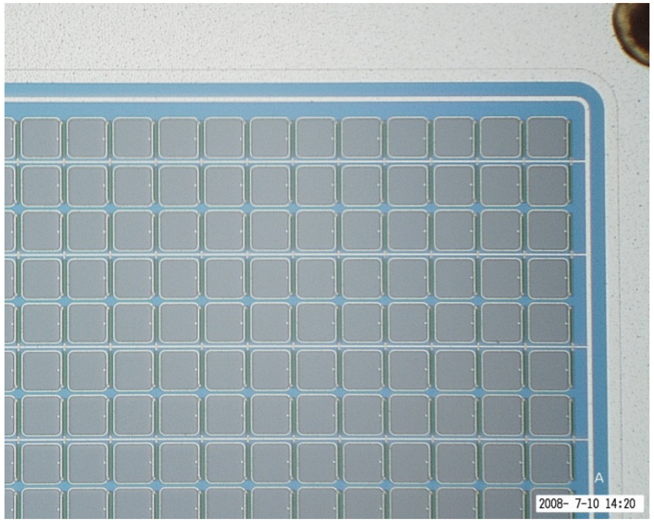
Purpose

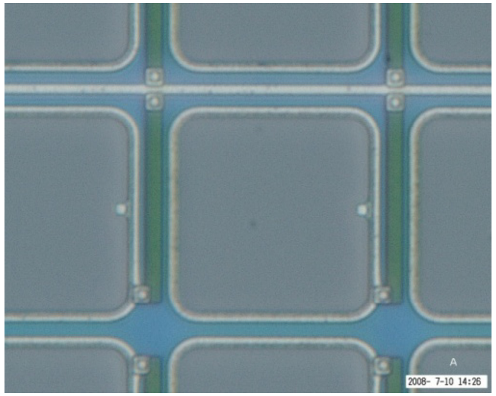
To understand the mechanism and suppression of the high dark-pulse generation

check items
- **threshold dose of I_{leak} increase**
- **hot spots**
- **position dependence of gains in a pixel**

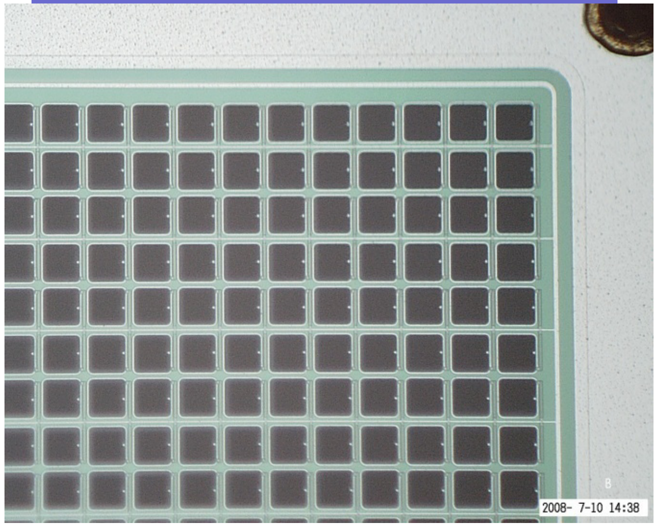
Special samples for γ-ray irradiation

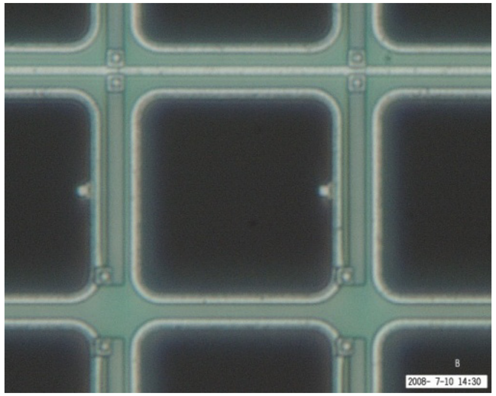
sample A



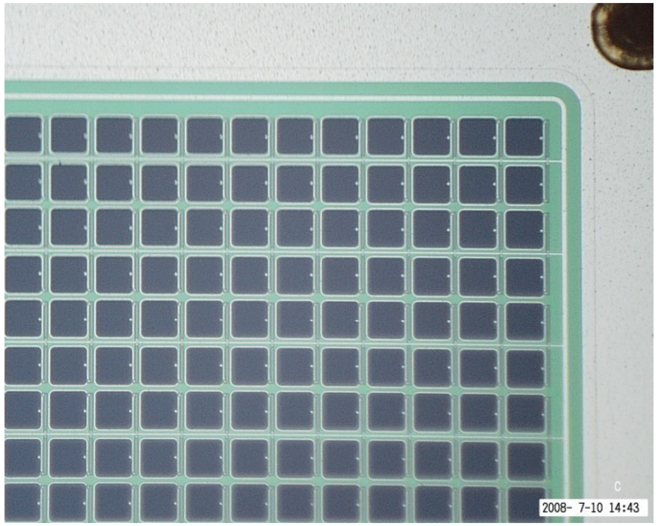


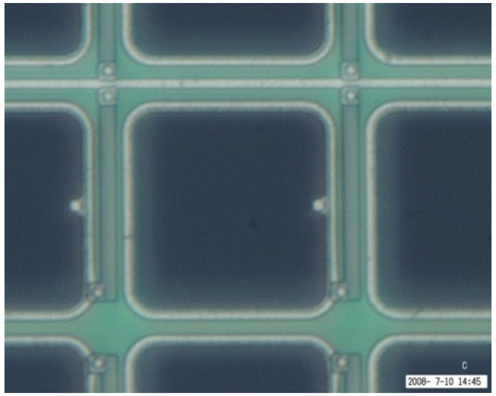
sample B (on-market product)





sample C

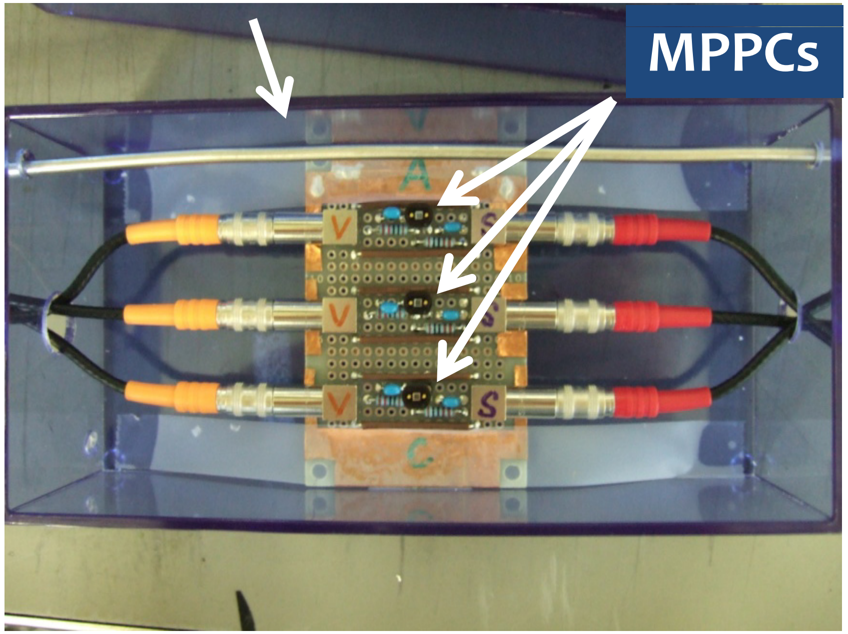




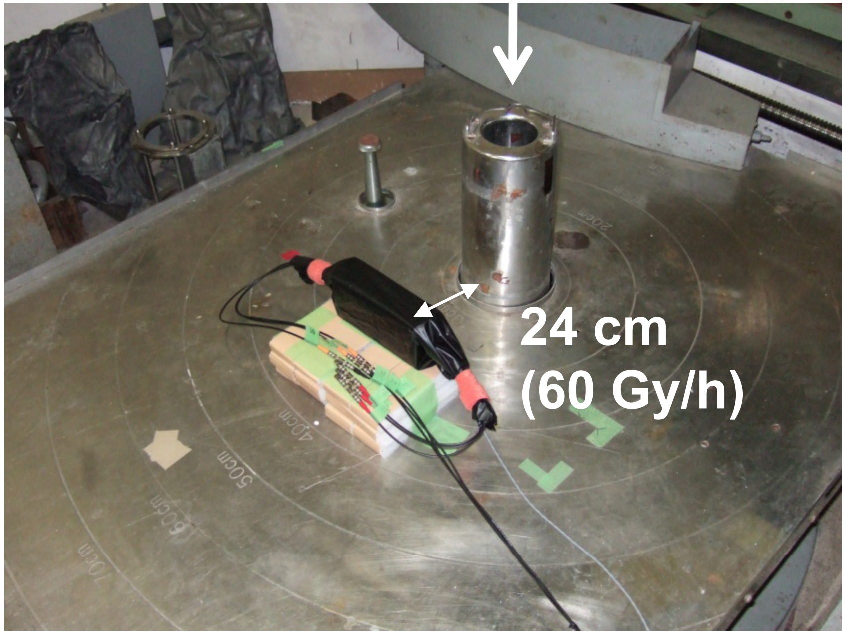
- structural difference has not been informed from the manufacturer at present.

Setup @ ^{60}Co facility (Tokyo Inst. Tech.)

thermometer (Pt)



^{60}Co source (10 TBq)



- **Simultaneous irradiation to the 3 samples (A, B, C)**

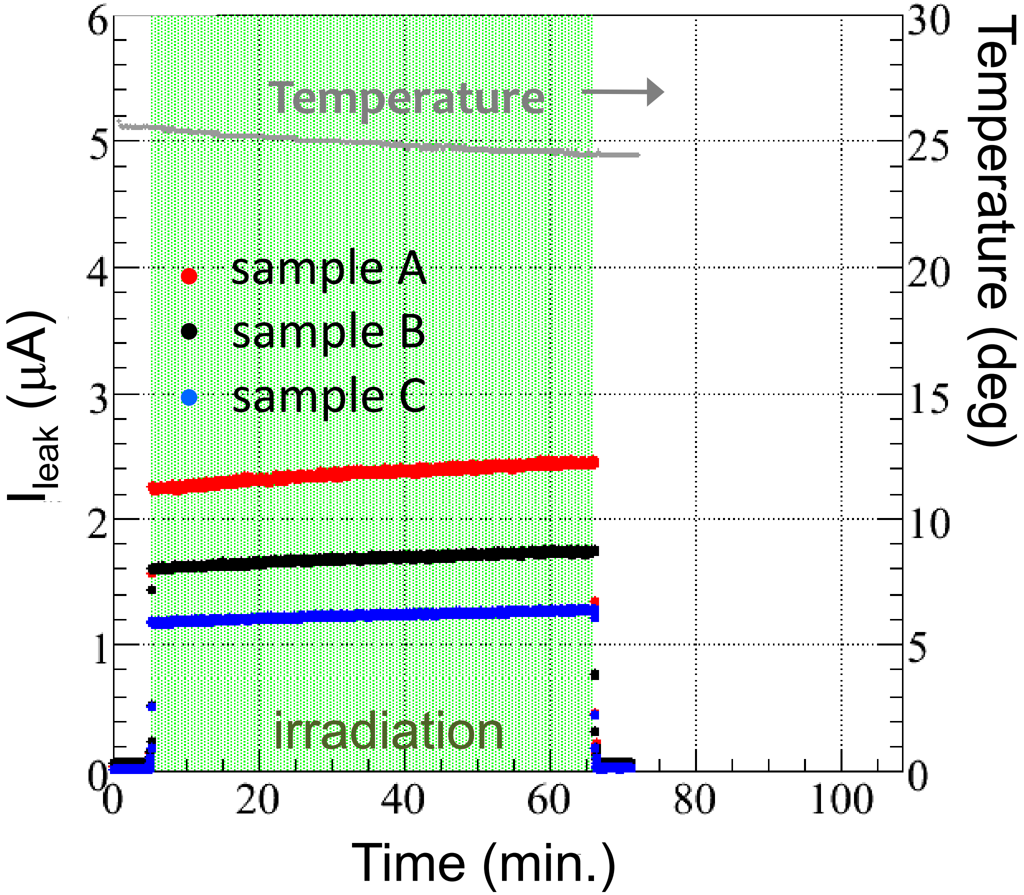
- **Dose rate : 60 Gy/h** (for air-equivalent materials)
- **Total irradiated dose : 600 Gy**

- Temperature fluctuation in the facility : **23 ~ 26 deg.**

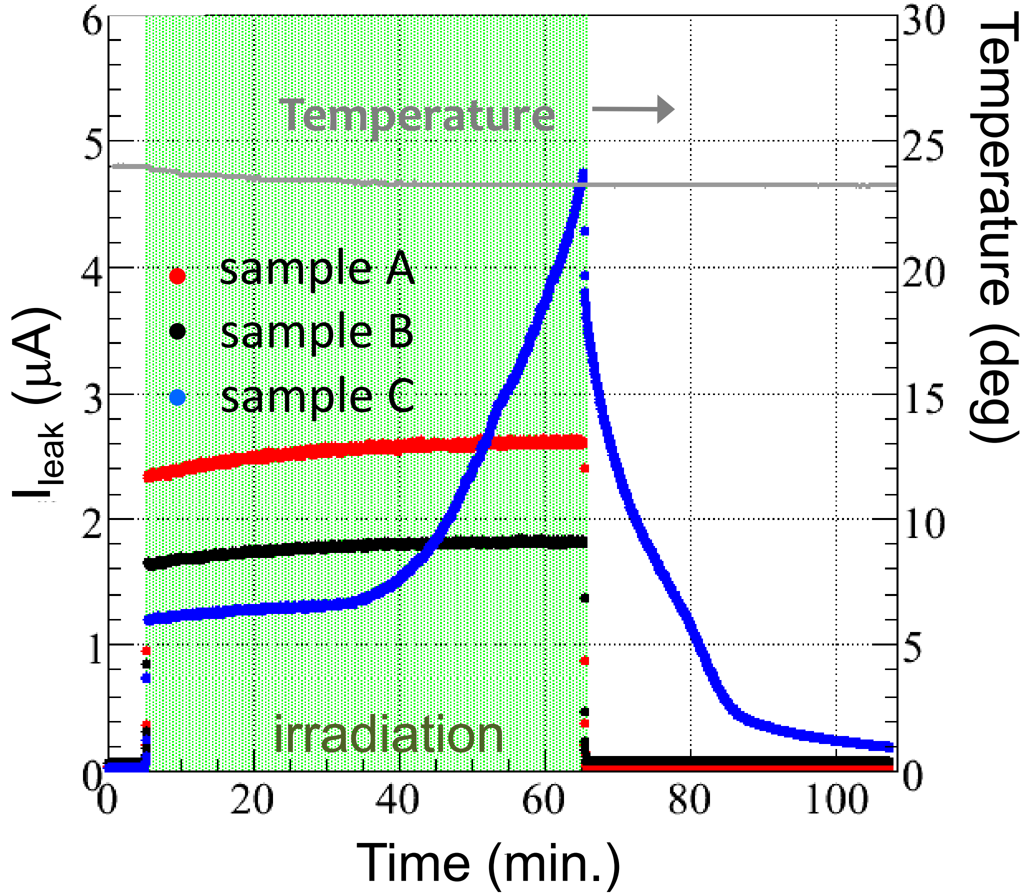
  Gain variation ... - 4.0 [%/deg] @ 25 deg

Time variations of I_{leak} (0-120 Gy)

(1) 0 – 60 Gy (60 Gy/h)



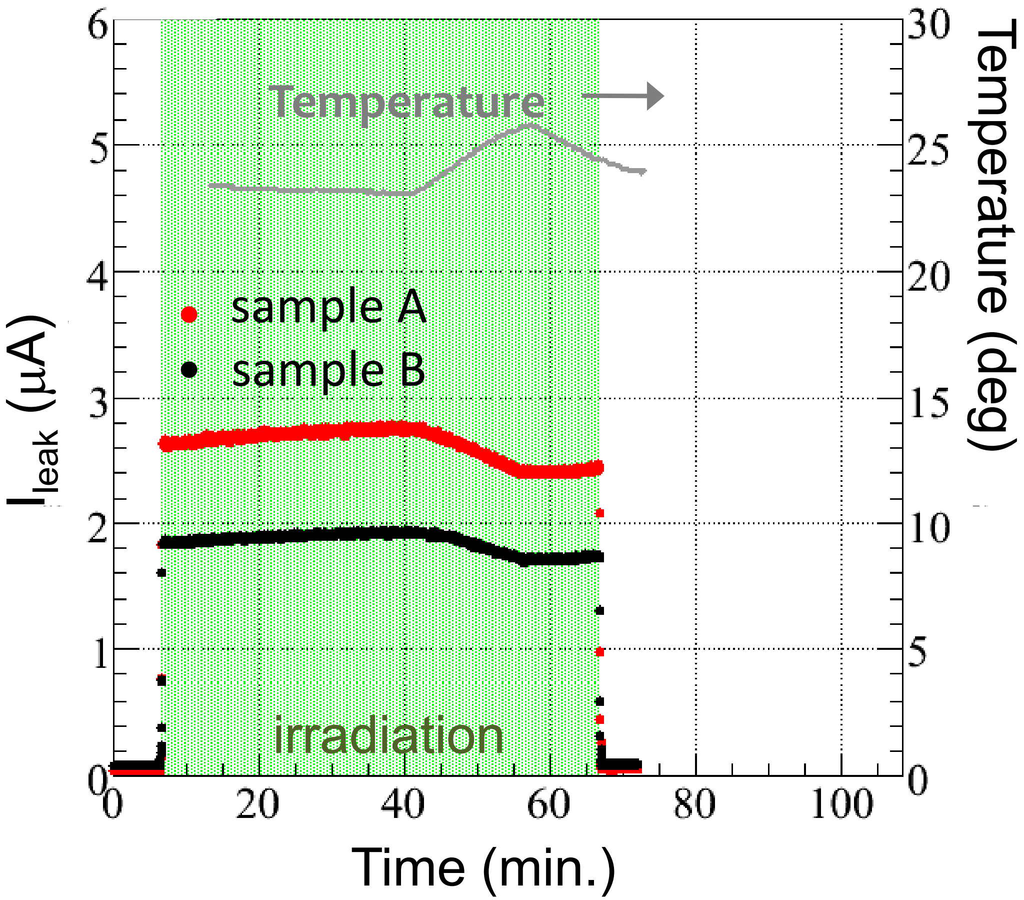
(2) 60 – 120 Gy (60 Gy/h)



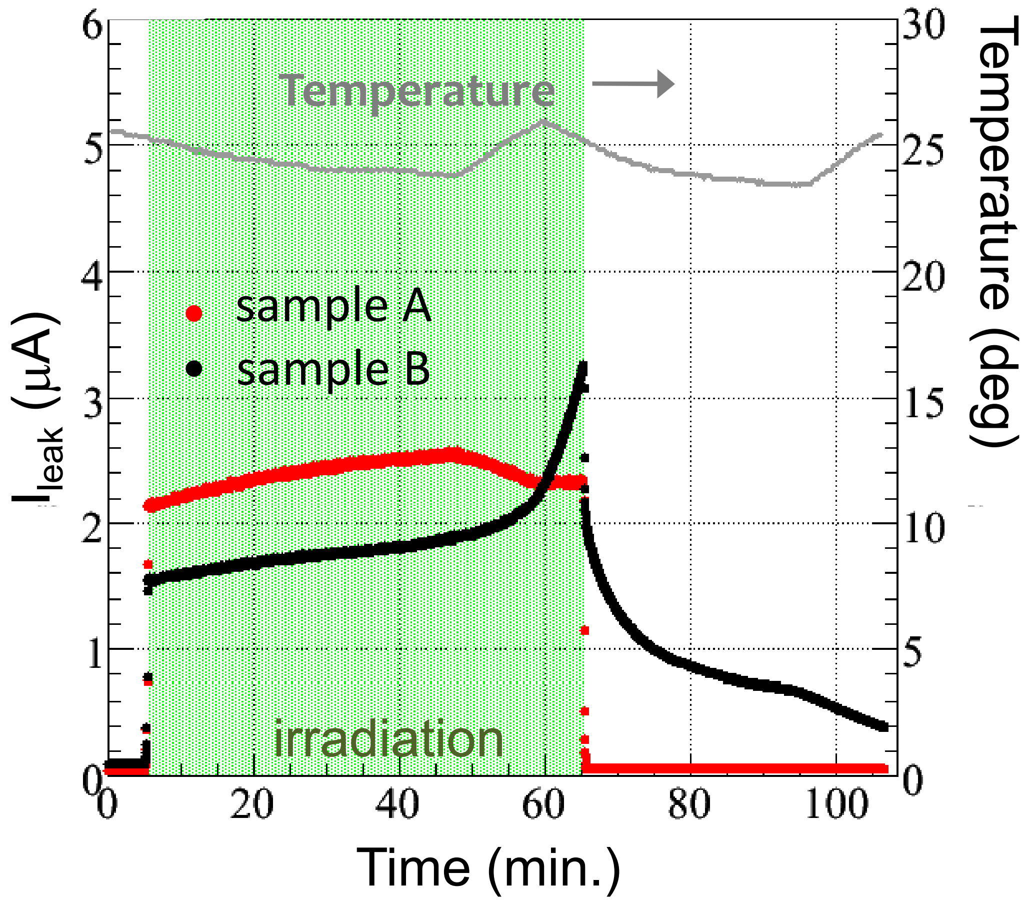
- Significant increase in I_{leak} of sample C **at 90 Gy**
  - recovery effect after the irradiation

Time variations of I_{leak} (120-240 Gy)

(3) 120 – 180 Gy (60 Gy/h)



(4) 180 – 240 Gy (60 Gy/h)



- Significant increase in I_{leak} of sample B **at 220 Gy**
  - recovery effect after the irradiation
- **No change for sample A at least up to 600 Gy**

Result of the γ-ray irradiation

Threshold doses for the leakage current increase

- sample C : ~ 90 Gy
- sample B : ~ 220 Gy **(on-market product)**
- sample A : **> 600 Gy**

(further irradiation for the sample A is planed at the end of this month.)

sample A is more γ-rays-resistant device than the on-market products.

Summary

- Radiation hardness is one of the issue to be made clear for a practical use of MPPC. The KEK-DTP has been performed a series of irradiation experiment with different rad. sources.

- **Mechanism of radiation damage**
  - neutrons / protons ： bulk damage is dominating.
  - γ-rays ： electric property change due to charge trapping near the Si-Insulator interface is dominating.

- **Our present work**
  - γ-ray irradiation for special samples with different structure to improve radiation hardness against γ-rays.
  - Result
    - **sample A was more γ-rays-resistant MPPC than on-market products.**