# Impact of external radiation on dark rate noise measurement for the Hyper-Kamiokande photomultiplier tube

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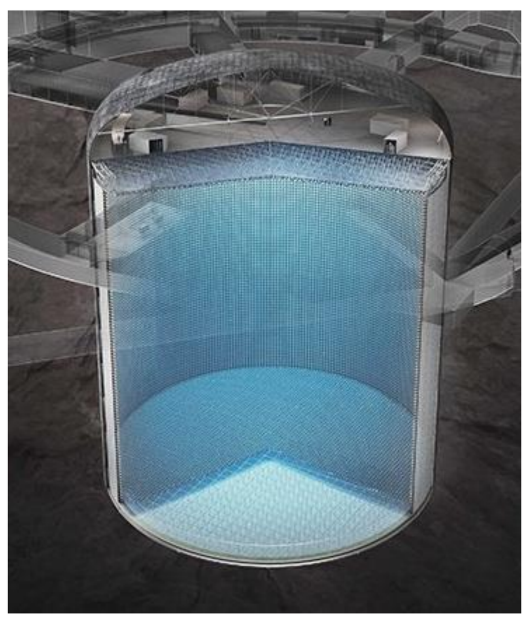
~20,000 improved 50 cm diameter PMT will be used for the Hyper-Kamiokande detector. The PMTs are currently under production and continuously delivered to Kamioka and tested there before installation. The result of the performance evaluation tests of the new PMT showed that the dark rate varied depending on the measurement location, which was attributed to difference in environmental radiation levels. Therefore, we evaluated the contribution from environmental radiation to dark rate measurement to estimate the intrinsic dark rate.

## 1. Introduction

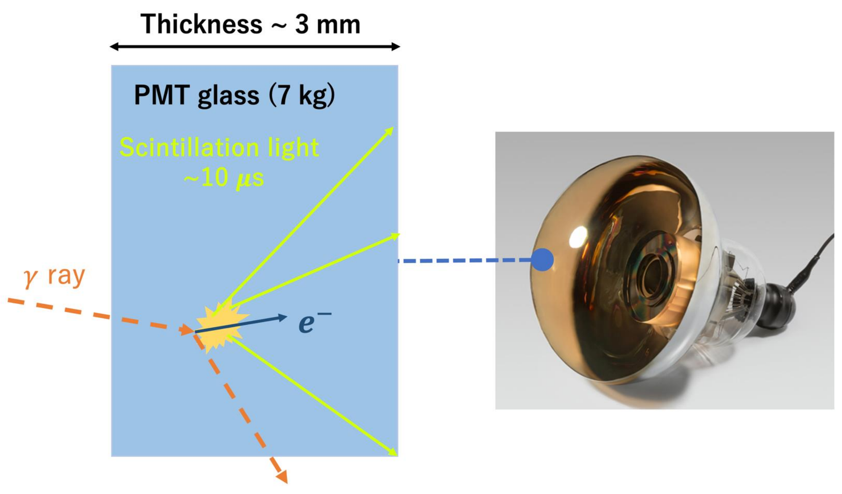
### 1.1 Hyper-Kamiokande (HK)

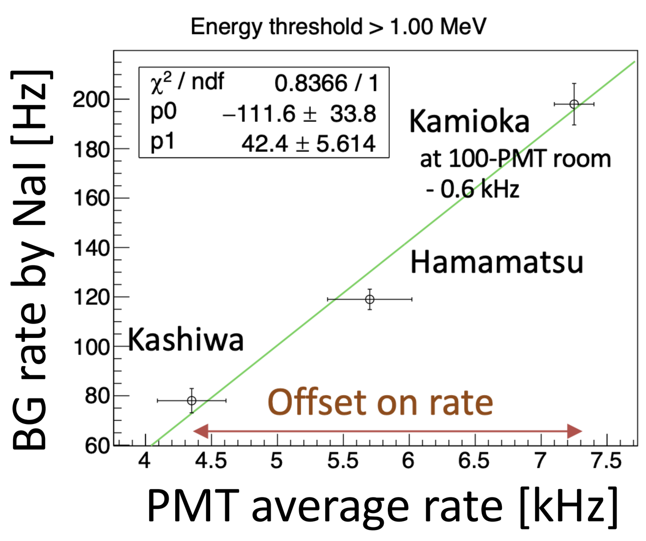


- HK is a next-generation water Cherenkov detector
  - Construction has started in 2020
    → Plan to start operation in 2027
- Detector design
  - Diameter 68 m × Height 71 m
  - Fiducial volume: 190 kton
  - ID wall is covered by 50 cm diameter PMTs

### 1.2 Performance testing

- PMT production and performance testing are underway.
- The measurements showed differences in dark rates depending location.
  - Kashiwa city: 4 kHz, Hamamatsu city: 6 kHz, Kamioka town:7 kHz
- It was found that there is correlation between the environmental radiation rate and the PMT dark rate for each location.
  - External $\gamma$-rays cause scintillation light in the PMT glass by which multiple signals are detected.



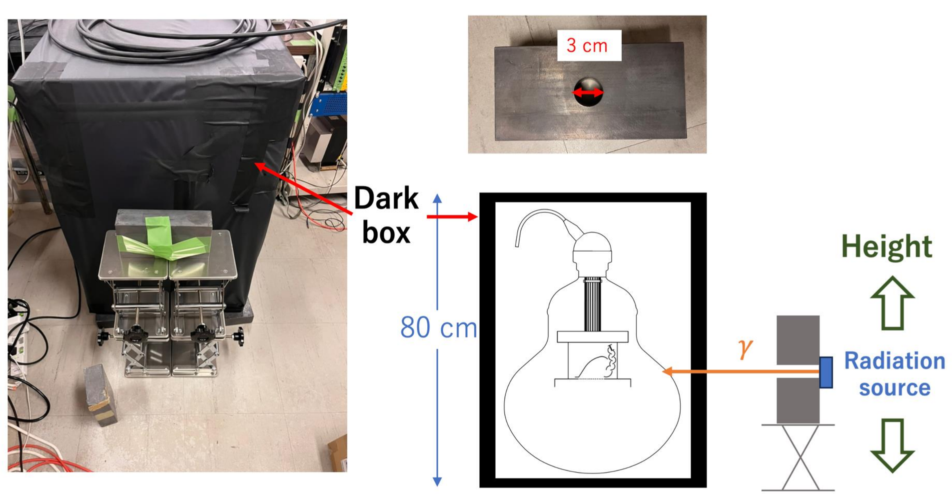

## 2. Setup of source measurement

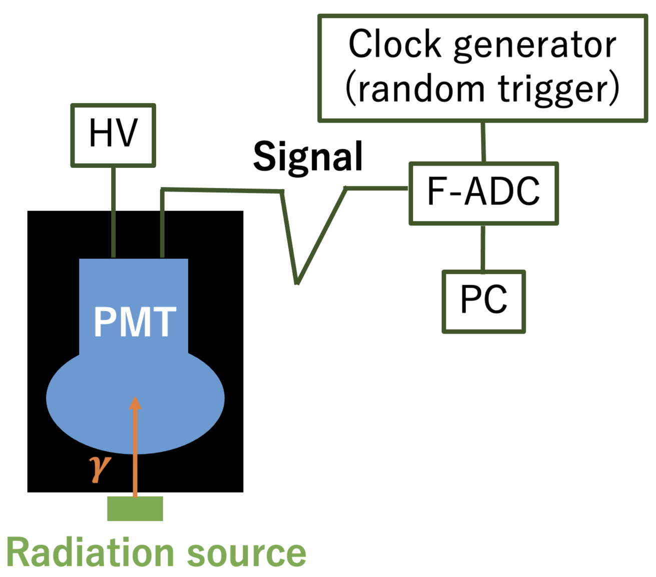
### 2.1 Measurement using a radiation source

- To investigate the effect of radiation on the dark rate, the PMT (Hamamatsu, R12860) was irradiated by a radioactive source.

Measurement setup

1. Variation of dark rate depending on the irradiation position of the radiation source
2. Changes in dark rate with $\gamma$-ray source at different energies

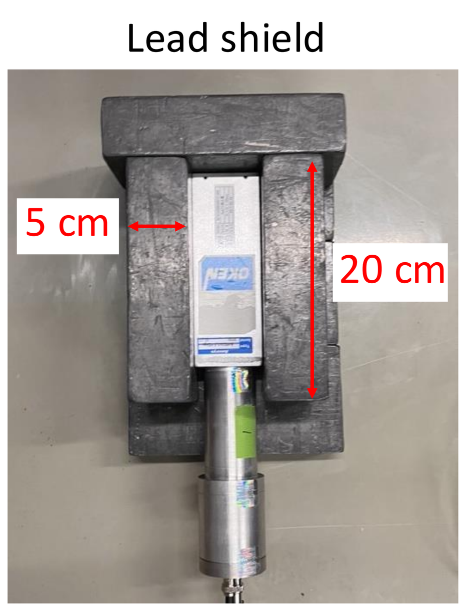


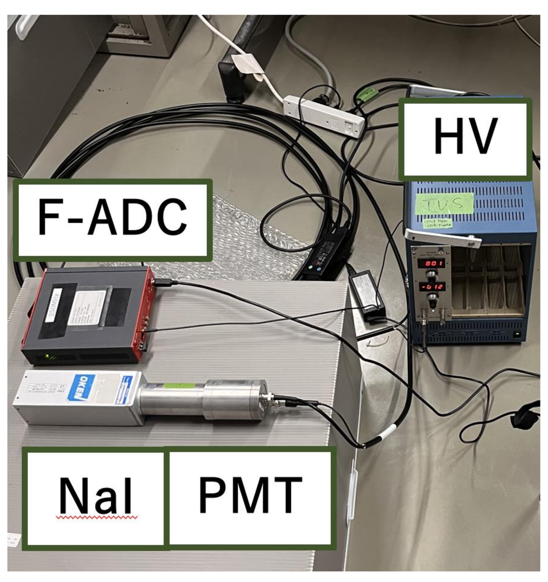

### 2.2 Environmental radiation measurement

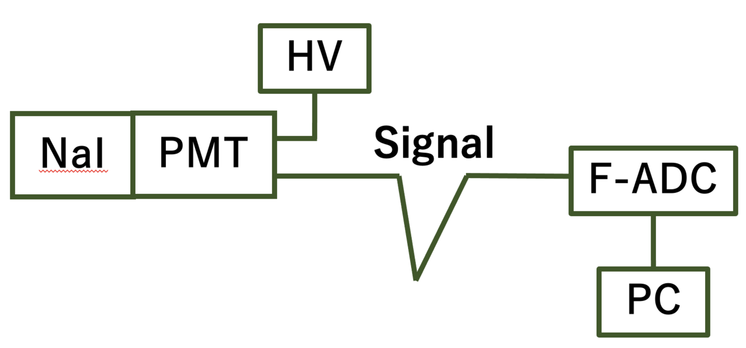
- Measuring environmental radiation using NaI scintillator.
- Measured w/ and w/o lead shielding to investigate self-radioactivity.

Lead shield




NaI:51×51×152 mm



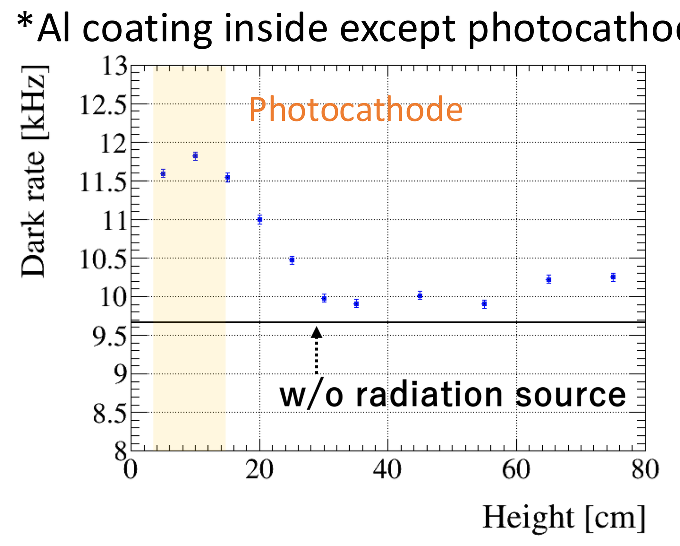



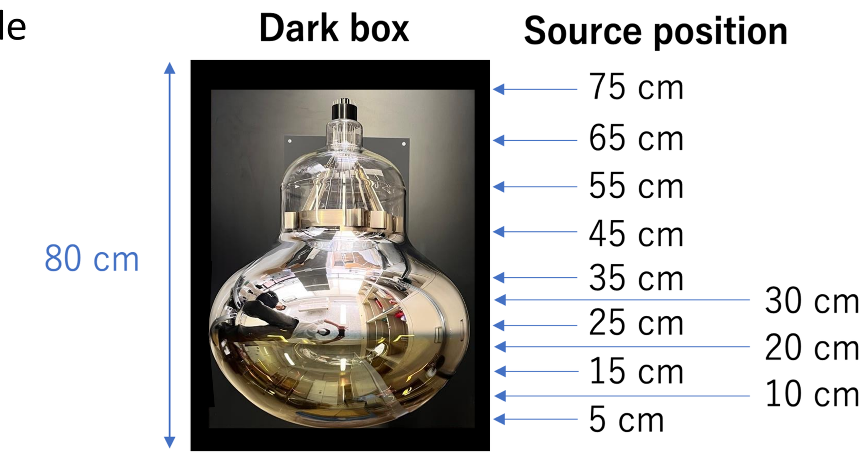

## 3. Measurement results

### 3.1 Measurement using a radiation source

1. Position dependence

*Al coating inside except photocathode



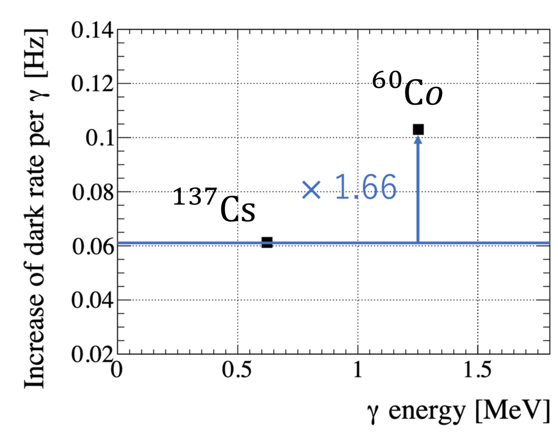




- Increase of the dark rate was significant when the photocathode region was irradiated.

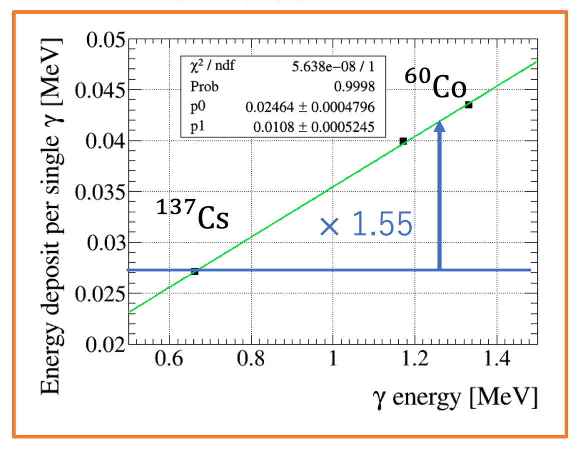
2. Energy dependence

Evaluated increased rates by two sources normalized with the decay rate and acceptance.

Measurement



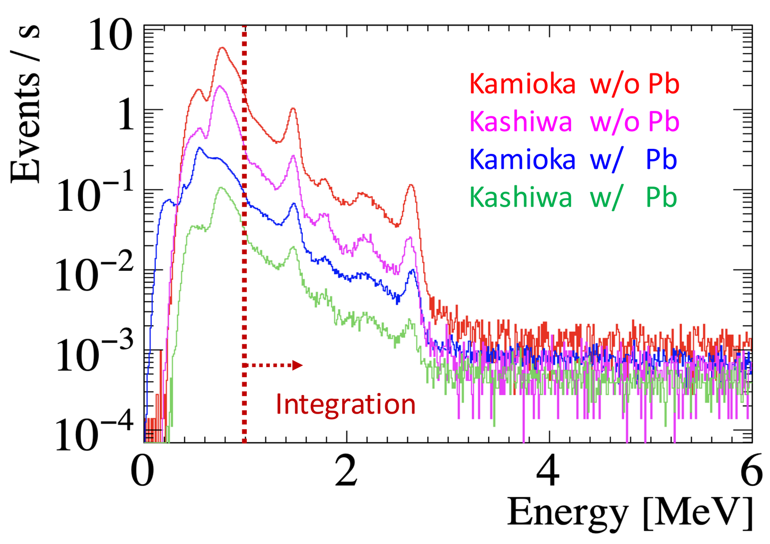

Simulation

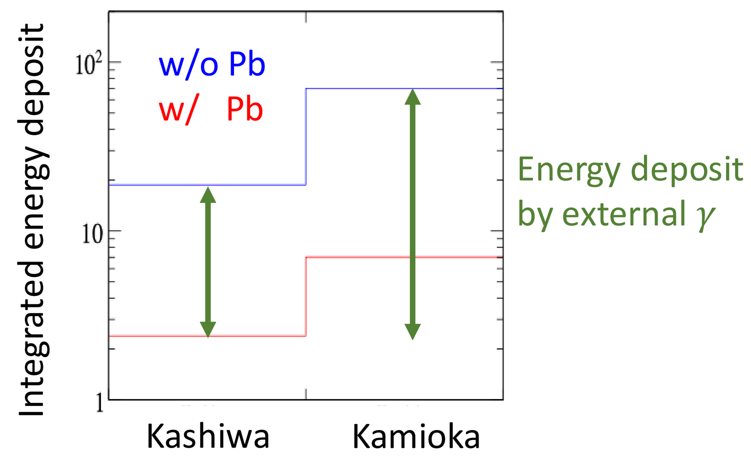



- Measurement show the increase of dark rate is proportional to $\gamma$-ray energy.
- Simulation show the energy deposit in glass is also proportional to $\gamma$-ray energy.
  → This indicate the increase of dark rate is due to scintillation light emission in PMT glass.

### 3.2 Environmental radiation measurement

- Energy distribution of environmental radiation measured with NaI.
- The lowest rate was obtained when using lead shield in Kashiwa.
  → We assumed this rate is due to environmental radiation inside NaI



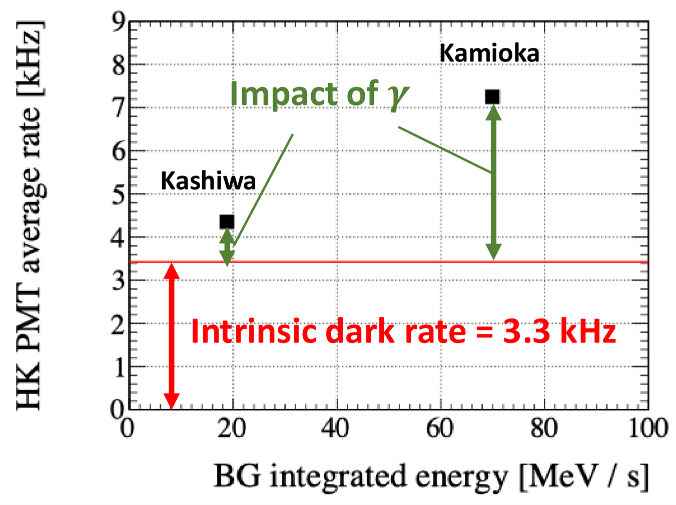




- The intrinsic dark rate is calculated by subtracting the contribution from environmental $\gamma$ at Kashiwa and Kamioka
- Assuming the ratio of energy deposit from NaI measurements at Kashiwa and Kamioka is proportional to the contribution of external $\gamma$ ray to the dark rate measurement

$$\frac{\text{Edep @ Kashiwa}}{\text{Edep @ Kamioka}} = \frac{\text{DR @ Kashiwa} - \text{intrinsic DR}}{\text{DR @ Kamioka} - \text{intrinsic DR}}$$

*DR (Dark Rate)

- The intrinsic dark rate value is estimated to be ~3.3 kHz.




## Summary

- Production and delivery of PMTs are underway for the start of the Hyper-Kamiokande experiment in 2027.
- During the PMT performance tests, dark rate was found to be different at each location.
- I used a $\gamma$-ray source to check the impact of external $\gamma$-rays to the dark rate measurement.
  - A correlation between $\gamma$-ray energy deposit in PMT glass (around photocathode) and increase of the dark rate was confirmed.
- The intrinsic dark rate value was estimated to be ~3.3 kHz after substruction of the contribution from external $\gamma$-rays.