PROCEEDINGS OF SCIENCE

Long-term performance and its stability of Hyper-Kamiokande PMTs in the SK water tank from 2018 to present

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For the Hyper-Kamiokande experiment, a new 50 cm Box & Line type PMT (HAMAMATSU R12860: HK-PMT) has been developed. Using PMT dark hit data taken for 129 HK-PMTs, which have been installed in Super-Kamiokande since 2018, long-term measurements of the gain variation of the HK-PMTs in the water were performed for the first time. As a result, we observed a gain increase of +0.79±0.03%/year for HK-PMT.

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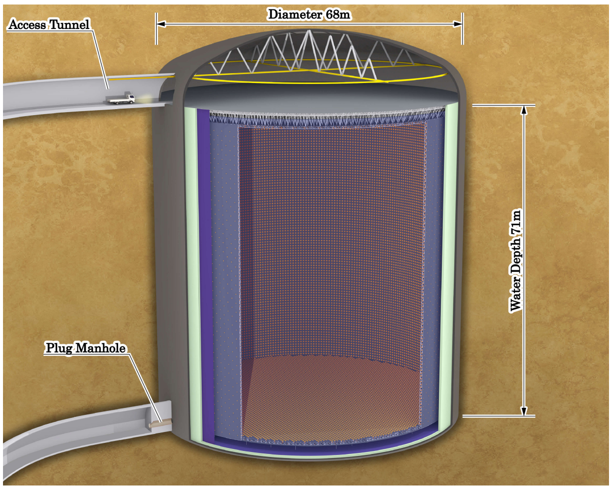

Figure 1: Hyper-Kamiokande detector, diameter:67 m, height:71 m, is filled with 258 kton pure water.

1. Hyper-Kamiokande photo-multiplier tubes installed in Super-K

The Hyper-Kamiokande is a next-generation water Cherenkov detector with a 68 m diameter, 71 m high cylindrical water tank that holds 258 kilotons of pure water [1][2]. The size of the water tank is five times larger than that of the Super-K, and its fiducial volume will eventually be eight times larger. Hyper-K's physics goals are precise measurements of neutrino oscillations using atmospheric and accelerator neutrinos to determine the CP phase, the mass hierarchy and θ_{23} -octant, observations of astrophysical neutrinos, and searches for nucleon decay. Hyper-K observes Cherenkov radiation emitted by charged particles from neutrinos and particle interactions, and reconstructs the events from the time information and light intensity. Detail information for Hyper-K can be found elsewhere[2]. For the Hyper-K experiment, a new 50 cm PMT with Box & Line type dynode (HAMAMATSU R12860; HK-PMT) was developed (Fig. 2). The developed PMT has improved detection efficiency and resolution compared to the PMT used in Super-K (HAMAMATSU R3600; SK-PMT). Compared to the SK-PMT, HK-PMT achieves 1.5 times higher quantum efficiency and 1.35 times higher collection efficiency, resulting approximately 2 times higher photon detection efficiency[3].

Performance of R12860 has been evaluated in the air for charge resolution, time resolution, dark rate, and detection efficiency. In order to evaluate long-term performance in the water as actual use, 136 HK-PMTs were installed in Super-K during Super-K renovation in 2018 , and data acquisition started in March 2019. The quantum efficiency and gain variation in the water have already been studied by using Ni-Cf calibration[4] data. In this study, the gain variation of the HK-PMTs in the water were performed with PMT dark hit data obtained from off-time window hits in cosmic muon events. Since this method has been originally used for the gain monitor of the SK-PMTs, it is adopted for gain monitor of the HK-PMTs in the Super-K water tank to measure the long-term gain variation. It allows for automated evaluation with more statistics, continuous data taking, and longer measurement periods than those by Ni-Cf calibration data.

Figure 2: HK-PMT; A new Box & Line PMT (HAMAMATSU R12860)

2. Data set and analysis methods

The data period used was taken from March 2019 to September 2022. The data acquired by the 129 PMTs were used for the analysis. Figure 3 shows the typical hit time distribution of 129 HK-PMTs for cosmic muon events. The peak corresponds to the arrival timing of Cherenkov photons emitted from a cosmic muon. Here we defined the off-time window from -3500 ns to 500 ns as shown in Fig. 3. The dominant part of the hits recorded in this off-time window is the signal due to PMT dark hits.

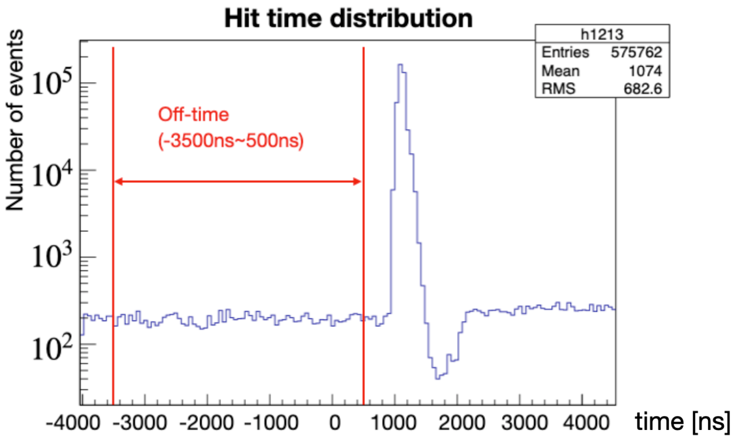

Figure 3: Hit time distribution of HK-PMTs.

The charge distribution of the hits for all the 129 PMTs in the off-time window is shown in Figure 4. A Gaussian fit was applied to this charge distribution to cover the peak region in 0.7 p.e. - 1.5 p.e. The peak value of the fitted Gaussian function was then plotted as a function of time (date) of data acquisition. A linear function is fitted to the result to quantitatively evaluate the gain variation (increase) by its slope.

3. Results

To confirm the validity of the present analysis method, we compared the gain variation of the HK PMTs installed in Super-K by Ni-Cf calibration data as shown in Fig. 5. The present analysis is

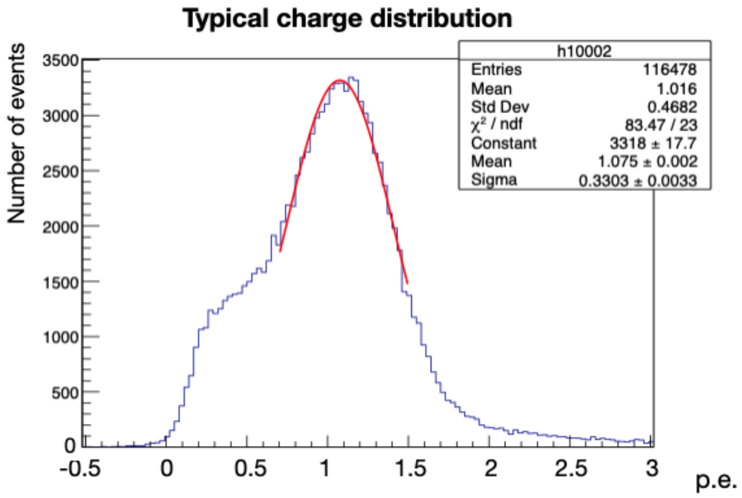

Figure 4: Charge distribution of dark hits data together with the red curve showing the Gaussian fitting result.

consistent with the result by Ni-Cf calibration data, demonstrating even much improved statistical accuracy.

As a result, the gain increase rate of the HK-PMTs was +0.79 ± 0.03 %/year as shown in Fig. 6. The gain increase was also measured for the SK-PMTs using the same method as a comparison as shown by the red points in Fig. 7. The rate of increase for the SK-PMTs was +1.42 ± 0.01 %/year, showing that HK-PMT and SK-PMT have a gain increase in the water but in different magnitudes.

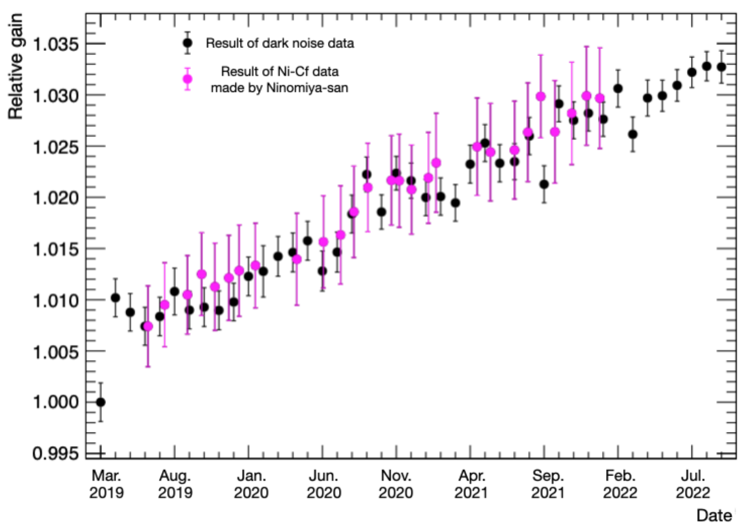

Figure 5: Gain time variation of 129 HK-PMTs with data acquired with dark noise data and Ni-Cf calibration data.

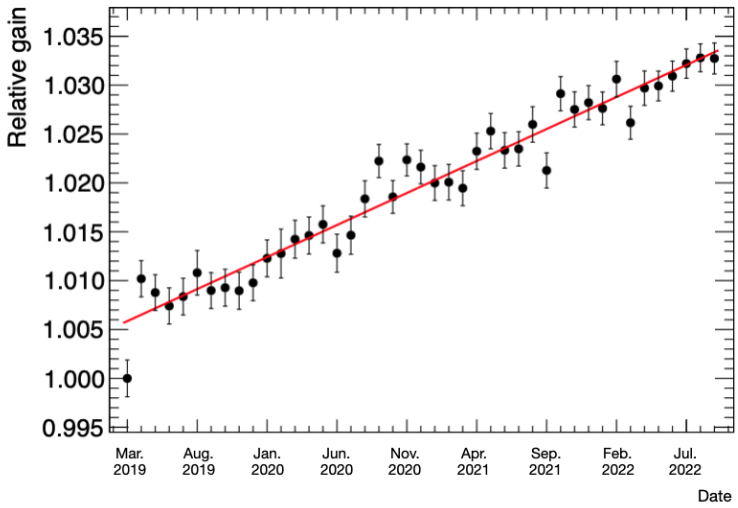

Figure 6: Gain time variation of 129 HK-PMTs with linear function fitting.

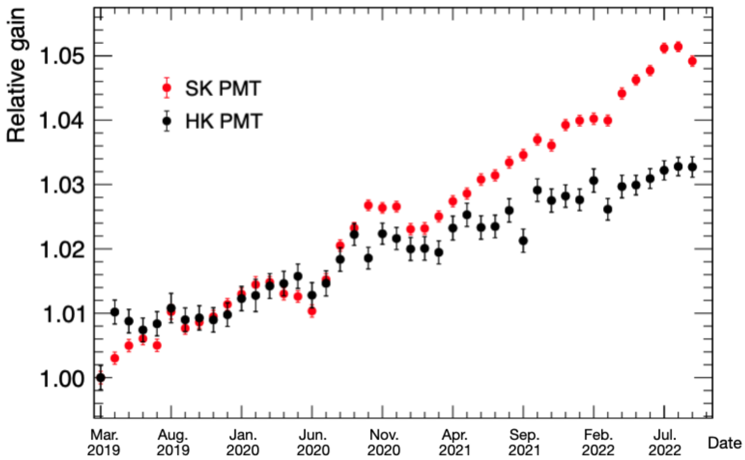

Figure 7: Gain time variation of 129 HK-PMTs and all SK-PMTs.

4. Summary

Over a hundred of HK-PMTs have been installed in Super-K since 2018. Long-term measurements of the gain variation of the HK-PMTs in the water were performed with PMT dark hit data obtained from cosmic muon events. As a result, we observed a gain increase of +0.79±0.03%/year for HK-PMT.

References

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