Evaluation of position dependent performance of 3-inch PMTs for Multi-PMT development

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Abstract. Hyper-Kamiokande detector is proposed as a next generation underground water Cherenkov detector in Japan, and is planned to be an order of magnitude bigger than its predecessor, Super-Kamiokande. In order to further improve the detector capabilities in both low and high energy sectors, the multi-PMT modules instrumented with multiple 3-inch PMTs are being developed, in addition to the improved high quantum efficiency 20-inch PMTs. We developed a moveable laser system that can illuminate different positions on the photocathode to measure the characterization of the 3-inch PMTs as a function of the position on the photocathode.

1. Hyper-Kamiokande experiment
Hyper-Kamiokande is the next generation of neutrino detector in Japan, based on the well-proven technologies employed and demonstrated by Kamiokande and Super-Kamiokande\textsuperscript{[1]}. It consists of a cylindrical shape water vessel which is 68 m in diameter and 72 m in length. Its fiducial volume is planned to be approximately 10 times larger than Super-Kamiokande. It detects the Cherenkov light produced by charged particles emerging from neutrino interactions in the water. The physics goals of Hyper-Kamiokande project include CP violation measurement, determining the ordering of the neutrino masses, observation of cosmic neutrino, and proton decay searches.

2. Multi-PMT module
Multi-PMT modules instrumented with 19 3-inch PMTs is considered for possible improvements in addition to newly developed 20-inch PMTs. According to the simulation studies, installing the multi-PMT modules enables higher vertex resolution due to the higher timing resolution than 20-inch PMTs. In addition, using smaller PMTs helps to distinguish the edge of Cherenkov ring with higher granularity than 20-inch PMTs especially for events close to the wall.

3. Performance evaluation of 3-inch PMTs
The measurement of 3-inch PMT was performed on the test bench shown in Figure 1. The 3-inch PMT R14374 developed by Hamamatsu is fixed inside the dark box. The optical fiber
is mounted on a moveable stand that can scan the PMT’s photocathode. The amount of light emitted from the laser oscillator is monitored by the monitor PMT.

Figure 1. The schematic view of the test bench (left) and the charge distribution (right).

3.1. Relative efficiency
Relative efficiency is evaluated by the ratio of the average number of photoelectrons detected by the 3-inch PMT to the amount of light in monitor PMT. The average number of photoelectrons is calculated from the charge distribution shown in Figure 1. Figure 2 shows the result of relative efficiency measurement. Relative efficiency is uniform within ±10% beside the edge of the photocathode. There is no correlation to the arrow in Figure 2, which shows the direction from the first dynode to the second one.

Figure 2. Relative efficiency measurement (left) and gain measurement (right).
3.2. Gain
Gain is evaluated by the charge difference between 1 p.e. and pedestal in Figure 1. The result of gain measurement is shown in Figure 2. Gain is about 10% higher at the arrow head which corresponds to the second dynode side.

3.3. Time response
Timing information is important to determine the vertex position. We measured two parameters to evaluate the time response of 3-inch PMT. The interval between the arrival time of photon on the photocathode and the time the electric signal is extracted from the anode of the PMT is defined as transit time (TT). Absolute value of TT measurement relies on the setup (e.g. cable length), but the position dependence can be measured. Transit time spread (TTS) is defined as FWHM of TT distribution. The results of time response measurement are presented in Figure 3. TT is about 0.5 ns shorter at second dynode side and TTS is about 0.5 ns smaller at first dynode side.

![Figure 3. Time response measurement. TT (left) and TTS (right).](image)

4. Summary
Tests were performed to evaluate the performance of 3-inch PMT as a function of the position on the photocathode. Relative efficiency is uniform within ±10% and is not correlated to the dynode orientation. On the contrary, gain and time response have some correlation to the dynode orientation. The orientation of the dynode of each 3 inch PMT should be recorded when installing the multi-PMT modules.

References
[1] Abe K et al. [Hyper-Kamiokande Proto-Collaboration], arXiv:1805.04163 [physics.ins-det].