Development of the Hyper-Kamiokande detector

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Hyper-Kamiokande (Hyper-K) is a next generation water Cherenkov detector planned in Kamioka, Japan [1]. It is an upgrade plan of Super-Kamiokande (Super-K), currently running to research various physics topics of neutrinos and nuclear decays. Fig. 1 illustrates the design of Hyper-K consisting of two tanks with dimensions 48 (W) × 54 (H) × 250 (L) m^3 for each tank. Its total (fiducial) volume is 1.0 (0.56) million metric tons, which is 20 (25) times larger than that of Super-K [2]. In the base line design, Hyper-K is equipped with 99,000 photo-detectors with a 50-cm diameter, and 25,000 photo-detectors with a 20-cm diameter for an outer veto layer to reject cosmic-ray muons. A research to construct the water tank underground and development to improve the detector performance are in progress for the actual detector construction in the very near future.

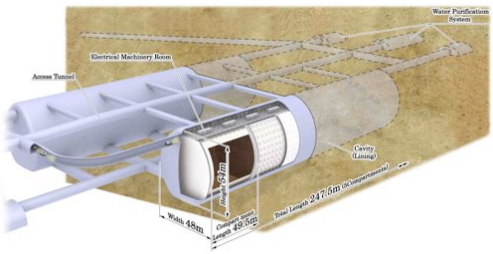


Fig. 1 Hyper-Kamiokande

The Hyper-K working group, consisted of more than 200 members, started a study to determine a concrete design of the cavity and tank construction, water circulation system, photo-detector, data acquisition system, software of the detector simulation, calibration, accelerator and a near detector in J-PARC for the neutrino long baseline experiment. Based on a geological survey at the candidate site in Kamioka, the cavern shape and tank structure are being optimized with considering a photo-detector supporter in water. The water circulation system to keep an ultra-pure water in Hyper-K is also designed with calculating a water flow and cycle.

One of the important studies to improve the Hyper-K performance is the photo-detector development, which could also improve the physics sensitivity not only by enlarging volume but also by a good resolution. Two types of new large-aperture photo-detectors with a high efficiency are currently under development. One is the photomultiplier tube (PMT) with a box-and-line dynode to acquire a good charge and time resolution, whereas Super-K uses the PMT with a venetian-blind dynode. Other candidate, a hybrid photo-detector (HPD) with an

avalanche diode, would bring an excellent resolution on charge and time with a low production cost expected.

The prototypes of 50-cm diameter photo-detectors showed an improved resolution compared with the Super-K PMT. Fig. 2 shows a single photoelectron peak, where a black line shows the Super-K PMT, the box-and-line PMT in a blue line and the HPD in red. A time resolution of these photo-detectors at single photoelectron is shown in Fig. 3. The good resolution of box-and-line PMT (blue) or HPD (red) implies an improved performance in Hyper-K.

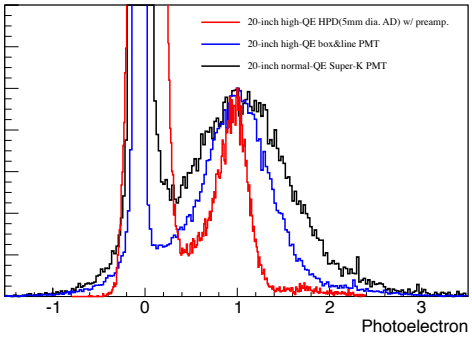


Fig. 2 Single photoelectron peak

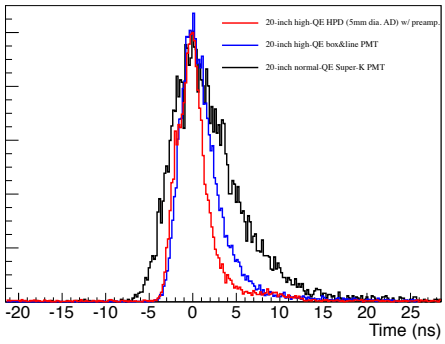
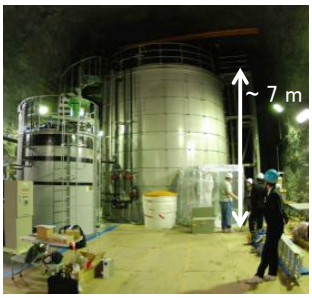
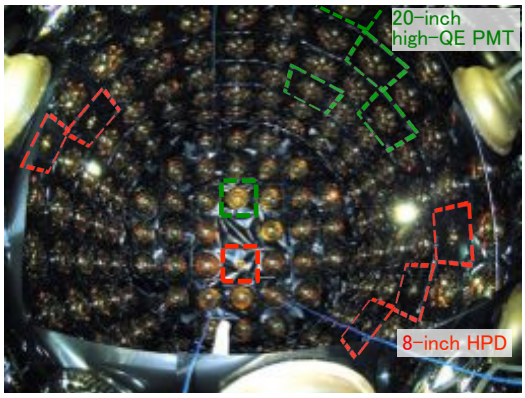


Fig. 3 Time resolution at single photoelectron

A usability of these new photo-detectors should be confirmed in advance so that the Hyper-K detector runs over ten years to achieve the target sensitivity without any trouble. A proof test started using a 200-ton water tank in Kamioka, Japan, to ensure a long-term operation and performance. Currently the HPD with a 20-cm diameter and the Super-K PMT with the high quantum efficiency improved from 22% to 30% are tested with the Super-K PMTs. The two types of new 50-cm photo-detectors will be also evaluated in the tank soon. In near future, structures of the photo-detector supporter frame, reflector and electronics will be tested in a small prototype detector of Hyper-K.



(a) Outside view



(b) Inside view from top

Fig. 4 The 200-ton water tank in Kamioka, constructed for the EGADS experiment. The 20-cm HPDs were installed in red boxes and the PMT with high quantum efficiency in green boxes.

The Hyper-K working group had a good progress of the detector R&D in a recent few years. Details of the Hyper-K detector design and recent activities such as the photo-detector development will be presented.

References

[1] K. Abe *et al.*, arXiv:1109.3262 [hep-ex] (2011).
[2] The Super-Kamiokande Collaboration, Nucl. Instrum. Meth. A **501**, 418-462 (2003).