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Hyper-Kamiokande: the next generation of neutrino detectors.

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Abstract

The next generation of water Cherenkov neutrino detector, Hyper-Kamiokande will take a unique role in neutrino astrophysics. The detector which has an effective volume 8.4 times larger than its predecessor, Super-Kamiokande, will be capable of observing proton decay, atmospheric neutrinos, and neutrinos from astronomical sources. The detector will be instrumented with new technology photo-sensors, faster and with higher quantum efficiency than the ones in Super-Kamiokande, its improved photon yield will enable superior signal efficiency and background rejection. This is particularly relevant for astrophysical neutrinos, such as the supernova burst neutrinos, supernova relic neutrinos, and solar neutrinos, allowing a much more precise study of their physics phenomena.

1 Introduction

Hyper-Kamiokande[1]-[3] is the next experiment, approved by the Japanese government, in the successful Kamiokande neutrino program. In 2020, the collaboration transitioned from a proto-collaboration to a real collaboration. Accordingly, the collaboration structure was reorganized for the construction work in the coming years. The number of collaborators has been increasing rapidly since the project approval, and it now involves a total of 493 researchers from 99 institutes in 20 countries participate as of January 2022.

Hyper-Kamiokande will be devoted to the search for nucleon decay as well as the study of neutrino phenomena and neutrino sources. Over the years, a series of water Cherenkov neutrino detectors have been built, beginning with the original Kamiokande detector[5] (1983-1996) and continuing with the Super-Kamiokande detector[4] (1996-). Hyper Kamiokande, like its predecessor Super-Kamiokande, will use the T2K long-baseline neutrino oscillation experiment as a far detector to measure the oscillations of neutrino and anti-neutrino beams generated at the Japan Proton Accelerator Research Complex (J-PARC)[6]. The detector will be capable of observing - far beyond the sensitivity of the Super-Kamiokande detector - precision neutrino oscillation with accelerator neutrinos and sun and atmospheric neutrinos, and neutrinos from astronomical sources. The expected potential for physics research and more detailed discussion are reported in [3].

2 Experiment design

2.1 The Far detector

The Hyper-Kamiokande detector will be located 600 m under the Mount Nijugo-yama in the Tochibora-mine at Kamioka, Japan. It will consist of a cylindrical tank with a diameter of 68 m and a height of 71 m, the schematic view of Hyper-Kamiokande tank is shown in Fig. 1. The experiment, which will be 8.4 times the size of its predecessor, Super-Kamiokande, will be filled with ultra-pure water, providing a fiducial volume of 188 kton. The tank is optically separated into 2 regions: the Inner-Detector (ID) and the Outer-Detector (OD). The ID consists of an array of 20,000 50 cm diameter photo-multiplier tubes (PMTs) which detect the Cherenkov light generated from events in the detector. This PMTs will provide 20% surface area coverage and have been developed by Hamamatsu (Hamamatsu R12860) with a high Quantum Efficiency photo-cathode and with a large Box & Line (B&L) type dynode to give 2.6 ns timing resolution. In addition to the 50 cm PMTs, 1,000 8 cm multi-PMTs (mPMTs) grouped in modules of 19 PMTs will be include to provide unique and complementary information to the 50 cm PMTs. Improving the position, timing and direction resolution of the detected events.

The OD will act as both, a passive shield for low energy backgrounds and an active veto for cosmic ray muons. The expected cosmic ray muon rate through Hyper- Kamiokande is around 45 Hz so this system is required to veto nearly 4 million muons per day. The OD region surrounds the inner detector, and is 1 m wide in the barrel region and 2 m deep at the top and bottom of the cylinder. It consist of 8,000 8 cm PMTs, each mounted within a $\sim$ 30% cm sided Wave Length Shifter (WLS) plates that serves to increase the coverage and collection efficiency.

2.2 The Neutrino Beam

The J-PARC beam-line that currently provides a 500 kW neutrino (anti-neutrino) beam to the T2K experiment will be upgraded over 1.3MW beam power in 2028. This will be achieved in two stages with a main ring power supply upgrade and a subsequent radio frequency upgrade to allow the repetition rate to be doubled.

2.3 Near detectors

There are near detector suites for monitoring the neutrino beam and studying neutrino interactions at the J-PARC site: The INGRID on-axis detector and the ND280 magnetized tracker. These detectors are an essential component of the long baseline experiment, allowing measurements to constrain the flux and neutrino interaction model uncertainty. The Hyper-Kamiokande project include upgrades of this detectors to improve the angular acceptance of the ND280 tracking detector.

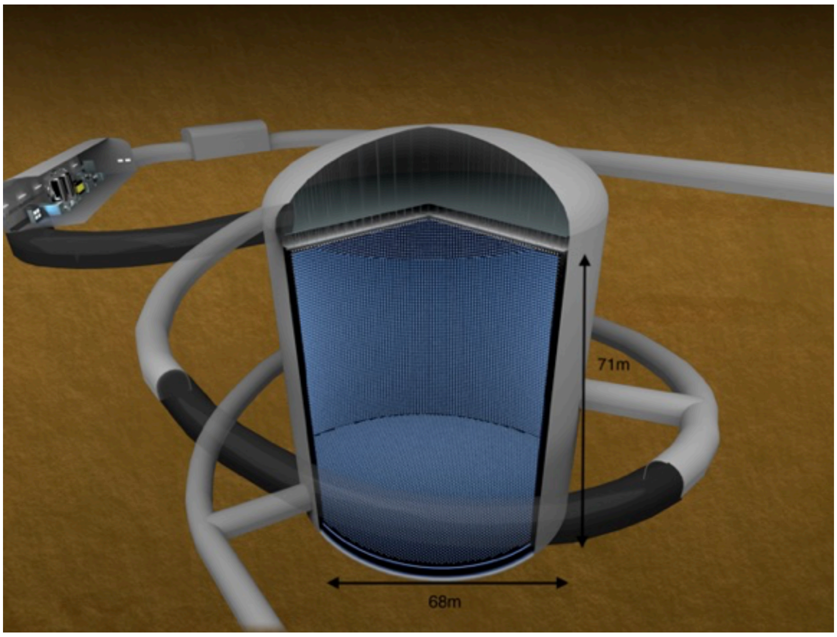

Figure 1: Schematic view of the Hyper-Kamiokande water Cherenkov detector. The tank will provide a volume of 260 kton of ultrapure water, with the dimensions of the 71 m $\times$ 68 m.

3 Current status of construction

Hyper-Kamiokande ground-breaking ceremony was held in May 2021. But in 2020, construction of the entrance yard and intensive geological surveys were carried out. The results indicated that the rock quality at the location of the main Hyper-Kamiokande cavity was excellent. The basic design of an underground facility was determined. Important milestones have been achieved since then: excavation of the access tunnel (1873 m) was initiated in November of 2021 and completed in February 2022. In 2021, mass production of the new 20-inch PMT commenced and was followed by the delivery of electronics and other equipment. In June of 2022, the tunnel excavation reached the center of the cavern dome and, the cavern dome excavation started in October of the same year. The construction of the tank structure is scheduled in 2024 and 2025, and the PMT installation will occur in 2026. Simultaneously, the power upgrade of the neutrino beam at J-PARC began during the shutdown period in 2021 and 2022. It is expected that the experiment start operations in 2027. The status of the experiment construction is shown in Fig. 2.

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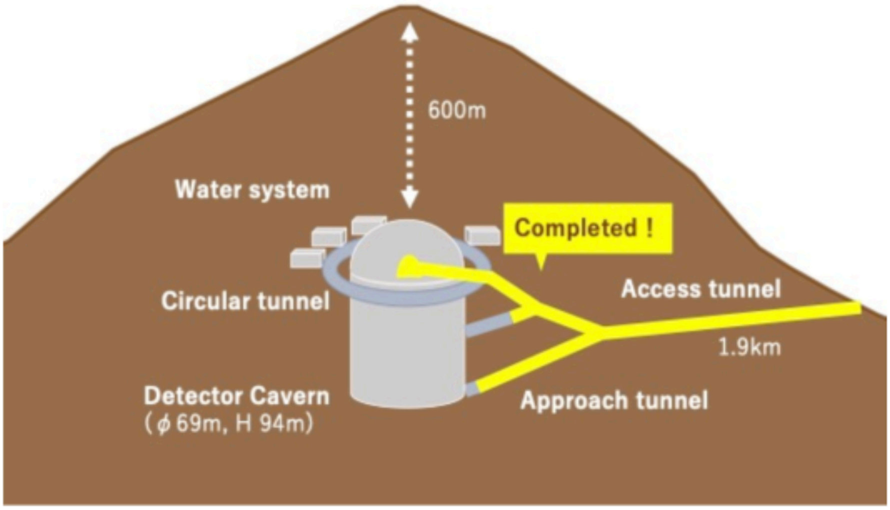

Figure 2: Construction status of Hyper-Kamiokande as of the summer of 2022.

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