PROCEEDINGS OF SCIENCE

Status, plans, and physics potential of the Hyper-Kamiokande experiment

Justyna Lagoda*

National Centre for Nuclear Research,
Pasteura 7, Warsaw, Poland

E-mail: justyna.lagoda@ncbj.gov.pl

Hyper-Kamiokande is a next-generation underground water Cherenkov detector currently under construction in Japan. Thanks to a fiducial volume more than eight times larger than that of the currently operating Super-Kamiokande, and enhanced detection capabilities, Hyper-Kamiokande is expected to significantly surpass the sensitivities of its predecessors, Super-Kamiokande and T2K. The project offers a comprehensive and ambitious science program. The experiment will investigate neutrino oscillations, using neutrinos from both natural sources—such as the Sun and cosmic ray interactions in the Earth's atmosphere—and an upgraded, intense neutrino beam produced at J-PARC, for which Hyper-Kamiokande will serve as the far detector. In addition, the experiment will explore neutrinos from astrophysical sources, including galactic core-collapse supernovae and the diffuse supernova neutrino background (DSNB). Hyper-Kamiokande will also conduct searches for rare processes such as proton decays. This article provides an overview of the Hyper-Kamiokande experiment, including its design, physics goals, projected sensitivities, and current status.

The European Physical Society Conference on High Energy Physics (EPS-HEP2025)
7-11 July 2025
Marseille, France

*Speaker

PoS(EPS-HEP2025)158

1. The Hyper-Kamiokande detector and its site

Hyper-Kamiokande (HK) [1] is a next-generation detector in the successful series of water Cherenkov experiments in Japan, following Kamiokande (operational from 1983 till 1996) and Super-Kamiokande (SK), which started operation in 1996). It employs a mature and scalable technology, enabling a rich and diverse physics program.

The detector, currently under construction in Japan, will have a total mass of 258 kilotons with a fiducial volume of 187 kilotons—about 8.4 times larger than SK. It will be located 600 meters underground in one of the largest human-made caverns. The dimensions of the cylindrical water tank will be 68 m in diameter and 71 m in height.

The inner detector will be equipped with approximately 20,000 20-inch photomultipliers (PMT), providing 20% photo-coverage. The new Hamamatsu Box&Line PMTs have improved dynodes and offer roughly two times better photon efficiency, charge and timing resolution compared to the PMTs used in SK, while maintaining a similar dark rate. Although they have also higher pressure tolerance, they will be protected from sudden pressure changes with acrylic covers.

In addition, about 800 of so-called multi-PMTs (mPMTs) will be installed to improve event reconstruction, in particular near the detector corners. Each mPMT consists of 19 3-inch PMTs enclosed together in a waterproof module.

The outer detector, one meter wide in the barrel and two meters wide on the top and bottom, and optically separated by Tyvek and black sheets, will be equipped with 3,600 3-inch PMTs mounted on wavelength-shifting plates to enhance Cherenkov light collection.

A stainless-steel frame will support the PMTs and mPMTs, as well as about 900 underwater electronics modules, each enclosed in waterproof vessels. The configuration is shown in Fig. 1. More information on the detector systems can be found in [2].

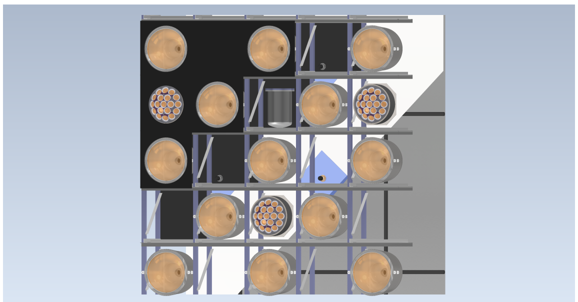

Figure 1: A schematic view of the stainless steel frame holding the PMTs, mPMTs, electronic vessels and Tyvek and black sheets.

The detector site is located 8 km south of SK, at the same distance of 295 km and an off-angle of 2.5° with respect to the J-PARC laboratory which will provide the high-intensity (anti)neutrino beam for long-baseline oscillation studies. The J-PARC beamline will be upgraded before the HK detector begins data taking. Already this year the neutrino beam for the T2K experiment reach a power of 830 kW and by 2028 it is expected to achieve 1.3 MW, thanks to an increased number of protons per pulse and a higher repetition rate. The power supplies for the magnetic horns have already been upgraded and now provide a current of 320 kA which allows for better focusing, resulting in 10% higher neutrino flux and a reduction of wrong-sign neutrino contamination.

HK will use the upgraded ND280 detector after the end of T2K experiment [3, 4], as well as a new movable Intermediate Water Cherenkov Detector, which will be located at the distance of 1 km from the target and cover the off-axis range of 1–4°.

2. The physics program

The physics program of the HK experiment is very rich. It includes studies of neutrinos from various sources—such as the Sun, Earth's atmosphere, supernovae, and J-PARC beam—as well as searches for diffuse supernova neutrino background and nucleon decay.

For solar neutrinos, HK will be able to accumulate a huge statistics of events, with an expected rate of approximately 5 ^{8}B neutrinos per hour. This large dataset will allow for precise measurements of Δm^2_{21} and of the day-night asymmetry caused by the regeneration of the electron component in Earth, leading to a few-percent higher event rate at night [5]. The magnitude of this asymmetry depends primarily on the value of Δm^2_{21}. Currently, a 1.5σ tension exists between Δm^2_{21} measurements coming from reactor experiments and global solar analysis [6]. If HK confirms this discrepancy, it may be a hint of the presence of new physics beyond the standard three-neutrino framework. The expected observation sensitivity as a function of exposure time is shown in Fig. 2.

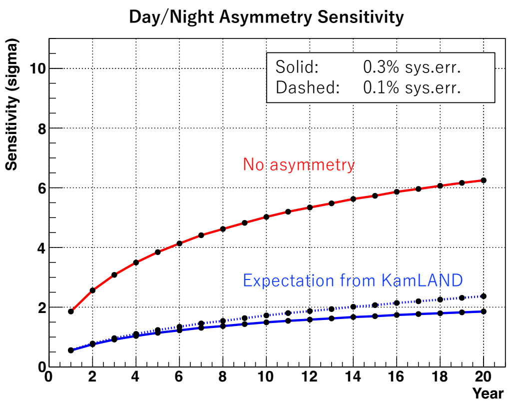

Figure 2: The sensitivity for day-night asymmetry (red line) and separate predictions based on the solar and reactor measurements (blue line) as a function of observation time. The solid and dotted lines correspond to the systematic error of 0.3% and 0.1%, respectively.

HK will also allow to measure the spectrum of the solar neutrinos in the transition region between the vacuum-dominated and matter-dominated oscillations (the so-called spectrum upturn) and to distinguish the standard oscillation scenario from various exotic models. The sensitivity to this effect, for two assumed energy thresholds, is shown in Fig. 3.

Other possible studies of solar neutrinos include the first measurement of the *hep* component, which can provide more information on the Sun core, as well as time-variation measurement of the solar neutrino flux.

HK experiment will be capable of detecting neutrinos from a possible core-collapse supernova explosion through two main processes: elastic scattering of electron neutrinos from the neutronization peak on electrons, and the Inverse Beta Decay (IBD) for electron antineutrinos from the cooling phase. The first process provides information on the direction to the supernova, with an accuracy

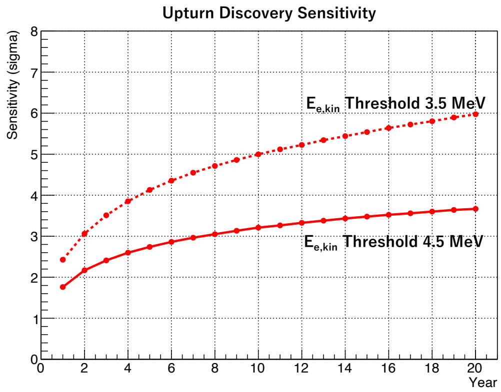

Figure 3: Spectrum upturn discovery sensitivity as a function of exposure time. The solid line corresponds to an energy threshold of 4.5 MeV, while the dotted line to that of 3.5 MeV.

of 1–1.3° for an explosion at a distance of 10 kpc. The expected number of detected events is about 70,000 for a supernova at 10 kpc, and 2,000–3,000 for the location of the SN1987a. Such a large sample will allow to measure the energy spectrum and time profile of the incoming neutrinos, and to extract information on the neutrino oscillations and properties (mass, mass ordering), as well as provide information valuable for core-collapse supernova modeling [7]. Moreover, since neutrinos arrive earlier than photons, the HK signal will provide an early warning for optical telescopes.

The HK detector will also search for neutrinos emitted from all past core-collapse supernova explosions (the Diffuse Supernova Neutrino Background). The expected flux is very low, of the order of a few tens of neutrinos per cm^2 per second. The search sensitivity is limited by the background coming from spallation at lower energies and from atmospheric neutrinos at higher energies. The first detection of relic neutrinos may come from the SK experiment doped with Gadolinium (SK-Gd); however, HK will perform search in a complementary energy range (16–30 MeV) compared to SK-Gd (10–20 MeV) and may measure the spectrum. Such data would contribute to our understanding of star formation history, metallicity and the fraction of black-hole forming supernovae. The expected number of IBD events is presented in Fig. 4.

Studies of atmospheric neutrinos, which cover a wide range of energies and baselines, provided in the past the first evidence for neutrino oscillations [8]. HK will further advance this field by possible determining the neutrino mass ordering using neutrinos in the 6–12 GeV energy range, where the matter effects in the Earth enhance oscillations [9]. In the case of normal (inverted) ordering, one expects an enhancement of the $\nu_\mu \to \nu_e$ ($\bar{\nu}_\mu \to \bar{\nu}_e$) oscillations, with the magnitude depending on the θ_{23} mixing angle. The δ_{CP} parameter primarily affects oscillations at around 1 GeV. With an expected rate of about 80 atmospheric neutrino events per day, HK will be able to reject the wrong mass-ordering hypothesis with a sensitivity of 2.2–4.9σ, depending on the true value of θ_{23}, and resolve the θ_{23} octant at the 3σ level (if $|\theta_{23} - 45°| > 4°$) after 10 years of data taking (corresponding to an exposure of 1.9 Mton · years). A combined analysis of beam and atmospheric data will further improve these sensitivities to 3.8–6.2σ for mass ordering and 3σ for the octant if $|\theta_{23} - 45| > 2.3°$ [1].

Other studies possible to perform with atmospheric neutrinos include tau neutrino appearance

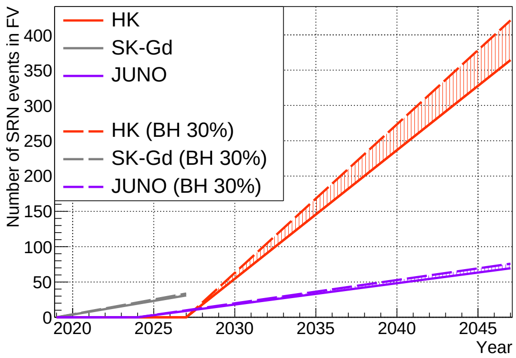

Figure 4: Expected number of IBD reactions from relic supernova neutrinos in several experiments as a function of time. Red, gray and purple lines shows Hyper-Kamiokande, SK-Gd, and JUNO, respectively. Solid lines correspond to the case, in which all the core-collapse supernovae emit neutrinos with the same spectrum, while dashed lines—to the case in which 30% of the supernovae form black hole and emits higher energy neutrinos.

and cross-section measurements, searches for exotic physics, such as Lorentz invariance violation and non-standard neutrino interactions, as well as measurements of the primary atmospheric neutrino flux.

The sensitivity for the beam-only analysis was reported by another speaker and can be found in [10, 11].

Another goal of HK is the search for nucleon decay, predicted by many Grand Unified Theories. Among the possible decay channels, the $p \to e^+\pi^0$ mode, favoured by several theories, can be fully reconstructed in a water Cherenkov detector, enabling a highly efficient and nearly background-free search. HK is expected to reach lifetime limits of about $6 \cdot 10^{34}$ years (90% C.L.) after 10 years of operation, and up to 10^{35} after 20 years (see Fig. 5a). Another important decay channel which can be studied, $p \to \bar{\nu}K^+$, predicted in supersymmetric models, is more challenging because the kaon momentum is below the Cherenkov threshold. Nonetheless, the expected limit after 10 years of HK operation is about $2 \cdot 10^{34}$ years (see Fig. 5b). For many other decays modes, an improvement by one order of magnitude is expected for the same exposure time.

3. Status

The HK experiment is currently under construction. The excavation of access tunnels and the detector cavern was completed in July 2025. Production of the PMTs is well underway, with about 12,000 of them already delivered and tested.

Construction of the far detector is scheduled to begin in 2026, with water filling expected in 2027. In parallel, upgrades of the J-PARC neutrino beamline and construction of the Intermediate Water Cherenkov Detector will be progressing. Data taking is expected to begin in 2028.

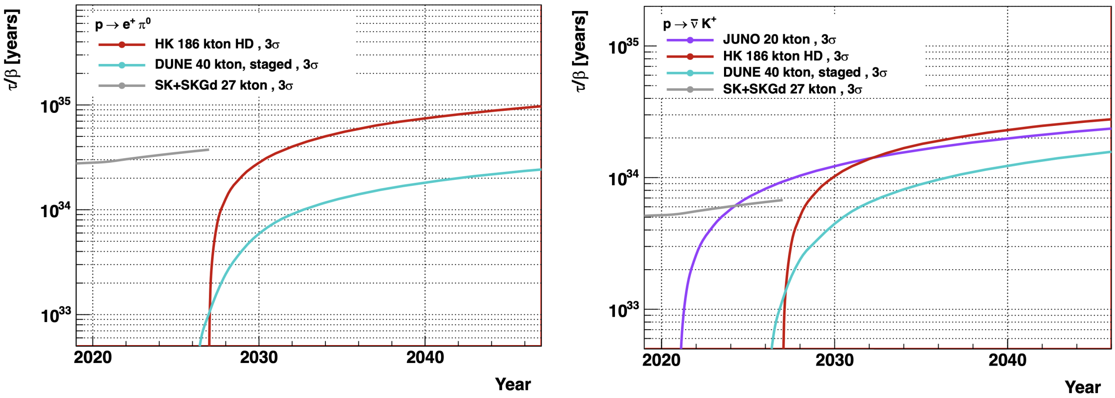

Figure 5: Expected 90% C.L. limits for proton decay in the $e^+\pi^0$ (left) and $\bar{\nu}K^+$ (right) modes.

Acknowledgments

This work was supported by the Ministry of Science and Higher Education (2022/WK/15), Poland.

References

[1] K. Abe et al. (Hyper-Kamiokande), arXiv: 1805.04163 [physics.ins-det].

[2] M. Guigue, "Status of the Hyper-Kamiokande far detector and timing system", PoS(EPS-HEP2025)508.

[3] K. Abe et al. (T2K Coll.), Nucl. Instrum. Meth. A 659 (2011) 106.

[4] K. Abe et al. (T2K Coll.), arXiv: 1901.03750 [physics.ins-det], CERN-SPSC-2019-001 (SPSC-TDR-006).

[5] A. Renshaw et al. (Super-Kamiokande), Phys. Rev. Lett. 112 (2014) 9, 091805.

[6] Y. Nakajima, 10.5281/zenodo.3959640.

[7] K. Abe et al. (Hyper-Kamiokande), Astrophys. J. 916 (2021) 1, 15.

[8] Y. Fukuda et al. (Super-Kamiokande), Phys. Rev. Lett. 81 (1998) 1562.

[9] L. Wolfenstein, Phys. Rev. D 17, 2369 (1978); S.P. Mikheyev and A.Y. Smirnov, Sov. J. Nucl. Phys. 42 (1985) 913.

[10] C. Dalmazzone, "Measurement of the CP violation in neutrino flavour oscillations with Hyper-Kamiokande", PoS(EPS-HEP2025)156.

[11] K. Abe et al. (Hyper-Kamiokande), arXiv: 2505.15019 [hep-ex].