Hyper-Kamiokande was approved!

Announcement from UTokyo, KEK, and J-PARC

The Hyper-Kamiokande project is officially approved.

February 12, 2020
The University of Tokyo
High Energy Accelerator Research Organization (KEK)
Japan Proton Accelerator Research Complex (J-PARC) Center

Hyper-Kamiokande (HK or Hyper-K) project is the world-leading international scientific research project hosted by Japan aiming to elucidate the origin of matter and the Grand Unified Theory of elementary particles. The project consists of the Hyper-K detector, which has an 8.4 times larger fiducial mass than its predecessor, Super-Kamiokande, equipped with newly developed high-sensitivity photo sensors and a high-intensity neutrino beam produced by an upgraded J-PARC accelerator facility.

The supplementary budget for FY2018 which includes the first year construction budget of 3.5 billion yen for the Hyper-Kamiokande project was approved by the Japanese Diet. The Hyper-K project has officially started. The operations will begin in 2027.

The overall Japanese contribution will include the cavern excavation, construction of the tank (water container) and its structure, half of the photo sensors for the inner detector, main part of the water system, Tier 3 offline computing, together with J-PARC accelerator upgrade and construction of a new experimental facility for the near detector complex. International contributions will include the rest of photo sensors for the inner detector, sensor covers and light collectors, photo sensors for the outer detector, readout electronics, data acquisition system, water system upgrade, detector calibration systems, downstream offline computing system, and the near/intermediate detector complex.

| Budget for large scale science projects, MEXT (funding agency) |  |
| 32.041 billion yen (fiscal year 2025) | 34.382 billion yen (fiscal year 2026) | 4.94 billion yen |

| 世界の学術フロンティアを先導する大規模プロジェクトの推進 |  |
| 目的 | 世界の学術研究を先導する。 |
| 国内外の研究機関を結び、国際的な研究課題を形成することにより、国内の研究機関における研究活動の共通基盤を提供。 |
| 日本科学技術庁において、科学的観点から策定したマスタープランに基づき、専門家集団が主導する選考過程において、開発の必要性・優先性を検討し、ロードマップを策定。 |
| ロードマップの策定より、大規模科学プロジェクトの推進を実現するプロジェクトを選定。国立大学法人運営交付金等の基礎的経費返済に、実行計画を策定し、審査会における選考を行って実施。 |
| 現在の137プロジェクトに加え、新たな研究の実施を促進する海外科学者等の新世代科学計画に新たに着手。 |

| 大規模学術フロンティア促進事業の主な事業 |  |
| 新エネルギー・産業技術総合開発機構の新エネルギー・産業技術総合開発機構（JST）の主導下で行われる。 |

| 新兴スパローネットワーク（SINE） |  |
| 日本国内の大学等を親企画・実施企業とするネットワーク形式の研究開発。 |

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- Construction started from early 2020
- Start operation from JFY2027
KamiokaNDE experiments

NDE = Nucleon Decay Experiment, or Neutrino Detection Experiment
Water Cherenkov detector

- Particle detection/reconstruction using Cherenkov rings
- Measurement of energy, direction, vertex from ring patterns
- Particle identification (<1% misidentification probability for e/µ)
- 4π uniform coverage with real time information
- Wide energy range: ~3MeV to 100GeV-TeV (SK)
- Scalable to larger mass, well established technology
Super-Kamiokande

50-kton water Cherenkov detector located at Kamioka, Japan

- Overburden: 2700 mwe
- Inner Detector covered by > 11000 20-inch PMTs
- Studying neutrinos from wide variety of sources:
  - Solar neutrinos
  - Supernova neutrinos
  - Atmospheric/Accelerator neutrinos

Operational since 1996, transitioning to SK-Gd

1996: Discovery of atmospheric $\nu$ oscillation
2001: Discovery of solar $\nu$ flavor change (with SNO)
2004: Accelerator $\nu$ oscillation evidence by K2K
2011: Discovery of $\nu_e$ appearance by T2K
2012: $\nu_\tau$ appearance in atmospheric $\nu$
2014: Indication of day/night effect in solar $\nu$

World-leading discoveries over >20 years

...and, still evolving!
Preparation work for upgrade in 2018-19

• Major refurbishment work 2018-2019:
  • Stopped water leak: < 1/200 of before (~1 m$^3$/d)
  • Many other improvements and cleaning

• SK-V operation (2019-)
  • The new Gd-water purification system tested
  • Successfully kept water transparency at a level similar to previous phases
  • Water flow tuning: Suppressed convection and expanded low-background region
SK-Gd has started!

**New water system for Gd-doped water**

13 ton was dissolved (0.01% Gd, 50% n-capture eff.)

**Introduced Gd-doped water from bottom**

Making 0.3°C temperature difference

**July 14-August 17, 2020**

**Rich physics program by much improved neutron tagging**

**Gd$_2$(SO$_4$)$_3$•8H$_2$O**

**Ex. Observation of relic supernova neutrinos**

Extends capability even after >20 years of operation

Great potential of water Cherenkov detector
From Super-K to Hyper-K

Hyper-KamiokaNDE 190kton fiducial

Super-KamiokaNDE 22.5kton fiducial

KamiokaNDE 3kton
1. Hyper-K detector to be built with **8.4 times larger fiducial mass** (190 kiloton) than Super-K and to be instrumented with **double-sensitivity PMTs**.

2. J-PARC neutrino beam to be upgraded from 0.5 to 1.3 Mega Watt
   - **x8** Natural Neutrino Rate and **x20** Accelerator Neutrino Rate

3. New and upgraded near detectors to control systematic errors

**Long baseline experiment and non-accelerator physics in a single project**
Broad science program with Hyper-K

- Neutrino oscillation physics
- Comprehensive study with beam and atmospheric neutrinos
- Search for nucleon decay
- Possible discovery with $\sim \times 10$ better sensitivity than Super-K
- Neutrino astrophysics
  - Precision measurements of solar $\nu$
  - High statistics measurements of SN burst $\nu$
  - Detection and study of relic SN neutrinos
- Geophysics (neutrino oscillography of interior of the Earth)
  - Maybe more (unexpected!?)

$\sim 3.5\text{MeV} \sim 20 \sim 100\text{MeV} \sim 1\text{GeV} \sim \text{TeV} \sim \text{MeV to TeV}$ with a single detector
The Hyper-Kamiokande detector

~8km south of Super-Kamiokande

260kton total water mass
190kton fiducial mass
I. INTRODUCTION

In the Design Report, physics performances with 40,000 of 20 inch PMT are described. This corresponds to 40% photo-cathode coverage on the inner surface of the inner detector. This value is the same as that of the Super-Kamiokande detector (40% photo-cathode coverage with ~11,000 of 20 inch PMTs), while as the photon detection efficiency of the new HK PMT is a factor two better than that of SK PMT, twice more hits or number of photo-electrons (p.e.) are expected in Hyper-Kamiokande for the charged particles with the same energies.

In addition to the new 20 inch PMT from Hamamatsu, use of two different types of photosensors are currently considered in Hyper-Kamiokande. One is 20 inch PMTs (called MCP PMT in this document) by North Night Vision Technology (NNVT) in China, and the other is Multi-PMT modules, which diameter is 20 inch in total but the module consists of 19 of 3 inch PMTs. This document describe the prospects of physics capabilities with different configurations of the photosensors, either with single type of photosensors or combination of two or three types of photosensors (quoted as “hybrid option”) as shown in Fig 1. Configuration with 20,000 of 20 inch PMTs is considered as the minimal setup, and referred to as the benchmark in comparisons.

Hamamatsu R12860

Newly developed for HK

Box&Line dynode

×2 better photodetection efficiency (QE×CE)

×2 better pressure tolerance

→ enable taller tank, design optimization

All PMTs will be tested >0.85MPa

Low dark rate (4kHz) and RI

×2 better charge resolution

×2 better timing resolution

(Performance in SK tank, 1.7e7 gain)
Improvement by the new PMT

Example: p→νK+, K+→μ+ν

- K⁺ (340 MeV/c) is below Cherenkov threshold
- K⁺→μ⁺ν (64%) : 236 MeV/c μ⁺ can be detected (with decay-e)
- Suppress background by tagging a 6 MeV γ from nuclear de-excitation
  - γ and μ signal separated by $\tau_{K⁺}$~12 ns
  - Better separation with better timing resolution
    $\rightarrow$ better efficiency (SK4: 9.1% → HK: 12.7%)
Finding evidence of GUT

Two modes as benchmark

Mediated by gauge bosons

\[ p \rightarrow e^+ \pi^0 \]

\[ \Gamma(p \rightarrow e^+ \pi^0) \sim \frac{g^4 m_e^5 g}{M_X^4} \]

SUSY mediated

\[ p \rightarrow \nu K^+ \]

\[ \Gamma(p \rightarrow \nu K^+) \sim \frac{\tan^2 \beta \times m_e^5 g}{M_d^2 \times M_3^2} \]

Of course, other possible modes are also important
Sensitivity to proton decay

\[ p \rightarrow e^+ \pi^0, 3\sigma \]

For $T_p/\text{Br} = 1.7 \times 10^{34}$ years, HK 10 years MC

\[ 0 < P_{\text{tot}} < 100 \text{MeV/c} \]

HK: $\mu^+\nu$ (eff. 12.7%) and $\pi^+\pi^0$ (eff. 10.8%)

30% efficiency, 1ev/Mt/year
JUNO: arXiv:1507.05613
65% efficiency, 0.05ev/20kt/year
Neutrino oscillation measurements

We learned a lot about neutrinos through neutrino oscillation, but many questions emerged and remains:

- Origin of tiny mass
- Why mass is much smaller than other fermions?
- Large mixing parameters
- Why so different from quarks?
- Symmetry behind the pattern?
- Mass hierarchy (ordering)
  - Which is the heaviest?
- CP violation
  - Is it violated just as in quarks?
  - Or new source exists?
- Extra neutrino families?

Properties of neutrino are considered to be connected with fundamental questions:

- Source of baryon asymmetry of Universe?
- Very high scale physics? (seesaw?)
- Origin of generations?
CP asymmetry measurement

- Comparison of \( P(\nu_\mu \rightarrow \nu_e) \) vs. \( P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \)
- T2K reports a hint of CP asymmetry, but some tension with NOvA
- Number of candidate \((\nu_e+\bar{\nu}_e)\) events \( \sim 100 \) for both experiments
- Plan to collect more data as well as combined analysis

\[ \nu_\mu \rightarrow \nu_e \quad \text{and} \quad \bar{\nu}_\mu \rightarrow \bar{\nu}_e \]

\[
\begin{align*}
\delta_{cp} &= 0^\circ, \text{NH, } \nu \\
\delta_{cp} &= 270^\circ, \text{NH, } \nu
\end{align*}
\]

(See talk by T.Nakaya) by A. Himmel @NEUTRINO2020  NOvA Preliminary
Neutrino oscillation measurements in HK

- Expect ~2000 candidate events for each of $\nu_e$ and $\bar{\nu}_e$
- Definite measurement of CP asymmetry
- ~10,000 events for $\nu_\mu/\bar{\nu}_\mu$
- Precision measurements of oscillation parameters
- Consistency check with other measurements
- $\theta_{13}$ from reactor experiments
- $\Delta m^2$ from reactor experiments
- Another way to determine mass ordering
- Different baseline/energy with NOvA and DUNE

Significance of CP

Hyper-K 10 years (2.70E22 POT 1:3 νe/ν$\mu$)

JUNO (reactor $\bar{\nu}_e$ at ~50km)

Hyper-K preliminary
True normal hierarchy (known)
$\sin^2(\theta_{13}) = 0.0218 \quad \sin^2(\theta_{23}) = 0.528 \quad \Delta m^2_{32} = 2.509E-3 \quad \delta_{CP} = -1.601$

Important to control systematic uncertainties in addition to statistics
J-PARC power upgrade

- **Shorter cycle**
  - $2.48s \rightarrow 1.32s \rightarrow 1.16s$
- **New power supply**
- **High gradient RF cavity**
- **Collimator improvement**
- **Rapid cycle pulse magnet for injection/extraction**
- **More protons / pulse**
  - Improve RF Power
  - More RF Systems
  - Stabilize the beam with feedback
- **Beamline upgrade** to handle high power beam
- Together with operation for T2K

**J-PARC beamline designed to realize the same off-axis angle for SK and HK**

**Power upgrade plan**
- $500kW \rightarrow 750kW \rightarrow 1.3MW$
Near and intermediate detectors

Near detector complex

- Designed beam center
- 1.5m ~10m
- INGRID on-axis detector
- ND280 off-axis detector

Intermediate Water Cherenkov Detector (IWCD)

- 1kton scale water Cherenkov detector at ~1km baseline
- Detector can move vertically → measurement at different off-axis angles

TPCs

SuperFGD

Upgrade for T2K (2022)

Further upgrade for HK (to be discussed)

Physics target

- \( \nu \)-int. measurement by off-axis scanning
- \( \nu_c \) cross section (3-5% for \( \sigma(\nu_c)/\sigma(\nu_\mu) \), \( \sigma(\nu_c)/\sigma(\nu_\mu) \))
- NC and intrinsic \( \nu_c \) BG measurement (3-4%)
- Neutron multiplicity with Gd loading

Linear sum to make monochromatic energy

Reconstruction

\( \nu \)-int. measurement by off-axis scanning
**Neutrino astrophysics**

- Observation of a few to 10 MeV neutrinos with time, energy and direction information
- Unique role in multi-messenger observation
- Solar neutrinos: up-turn at vacuum-MSW transition, Day/Night asymmetry, hep neutrino observation
- Supernova burst neutrino: explosion mechanism, BH/NS formation, alert with ~1° pointing
- Supernova Relic Neutrino (SRN): stellar collapse, nucleosynthesis and history of the universe

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**SRN rate**

- Calculation from FV and $E_{\text{th}}$
- Efficiency is not accounted

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**SN direction**

- ~70k $\nu/\bar{\nu}$ at 10kpc

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**Modulation induced by SASI**

- Statistical fluctuation in HK

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**Number of SRN events in FV**

- Year
  - 2020
  - 2025
  - 2030
  - 2035
  - 2040
  - 2045

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**Events/0.22Mt/20msec**

- Nakazato et al. (2015), 1D, 30M, BH
- Nakazato et al. (2015), 1D, 20M
- Takiwaki et al. (2014), 3D, 11.2M
- Bruenn et al. (2016), 2D, 20M
- Dolence et al. (2015), 2D, 20M
- Pan et al. (2016), 2D, 21M
- Tamborra et al. (2014), 3D, 27M
- Totani et al. (1998), 1D, 20M
More science topics

Indirect dark matter search

Neutrino oscillogram of Earth’s core

Constraints on the proton to nucleon ratio of the Earth’s outer core for a 10 Mton year exposure of Hyper-K
Construction has started

- Detailed geological survey
- Preparation of entrance of the access tunnel
- Detailed design of tunnel and cavern
- Production of PMT starts
- Power upgrade of J-PARC accelerator and neutrino beamline
- Investigation of near and intermediate detectors

New Power supply for J-PARC MR
Host institutions: The Univ. of Tokyo and KEK

Signed a MoU to promote the HK project (May 2020).


Project management organization is defied.

First meeting of Project Advisory Committee (PAC) was just held in September 2020

Chair: Toshinori Mori (ICEPP)

10 members (8 from outside Japan)

Other organizations are also being formed.
Hyper-Kamiokande Collaboration

- Transition from “proto-collaboration” to the full collaboration
- Collaboration Agreement
- Formed Institutional Board and selected Chair (Emilio Radicioni, INFN)
- Election of Spokespersons, Executive Board, … this year
- Definition of Construction Working Group and leaders

The last “Proto-Collaboration” Meeting, Feb. 2020

19 countries, 93 institutions, ~430 people
(1 year ago: 17 countries, ~300 people)

Europe: ~240  Asia: ~140  Americas: ~50
(Japan: ~110)
International effort for HK construction

Materials:

- VSZ
- IBTTVHHFTUFEBOFXSFGMFDUJWFNBUFSJBM
- dPG
- SFGMFDUJWJUZXBTDPOGJSNFEXJUI5PIPLV6OJW`TNFBTVSFNFOUTZTUFN
- 6TFECZ(&3%"BOE9&/0/5XBUFS$IFSFOLPWNVPOWFUP
- 5IFTFQSPEVDUT
- BSFJOBDDFMFSBUFEBHJOHUFTU

Specular Film DF

- 3MŒ SpecXlaU Film DF2000MA iV a
- multilayer polymeric film with specular reflection with greater than 99% photopic reflectivity. This is metal free, non-corroding and non-conducting product.

Parameters from datasheet:

- Total thickness (including liners and adhesive layer): 206 μm
- Thickness of the film: 66 μm

UV absorber

Light collector R&D

- (Russia & Japan)
- Conception of the light concentrator

New beam monitor

WC test experiment at CERN

Multi-PMT module:

(ref. KM3NET)
High resolution Cherenkov ring imaging essential for IWCD
Consider to use for part of HK

PMT + WLS plate (UK)

ID mockup at ICRR

Sync and clock system test bench at TokyoTech

Underwater electronics:
Case design and feedthrough

Linac for calibration
Developed in Poland

Linac proposal

Dedicated software
Simulation and reconstruction

Outer detector:

3-inch water proof PMT

PMT cover in Spain

Multi-PMT module:

(ref. KM3NET)
High resolution Cherenkov ring imaging essential for IWCD
Consider to use for part of HK

IWCD simulation

Prototype at TRIUMF

Electronics at INFN

mPMT in Memphyno water tank in France

Box&Line PMT in Super-K

20-inch MCP PMT:
Test in dark room

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Project timeline

FY2020: Geo. survey
FY2021: Access/Cavern design
FY2022: Cavern excavation
FY2023: Tank const.
FY2024: PMT installation
FY2025: PMT production
FY2026: Power line to entrance yard
FY2027: Entrance yard
FY2028: Upgrade of J-PARC accelerator and neutrino beamline

Near detector facility, R&D, production
ND construction

PMT cases, mirrors, electronics etc.
Water system
Filling water
Operation
Hyper-Kamiokande is the next generation water Cherenkov detector with a very broad science capability based on the success of Kamiokande and Super-Kamiokande. Proton decay (>10^{35} years), neutrino oscillation, neutrino astrophysics, …

Project was approved in 2020 and construction has started. International collaboration is working together for the start of experiment in 2027.