Hyper-Kamiokande UK

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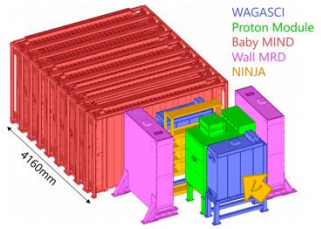
On behalf of the Hyper-K UK collaboration

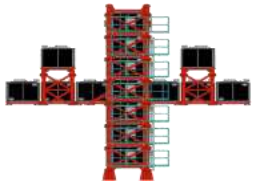
ECFA meeting, University of Durham, Sept. 2024.

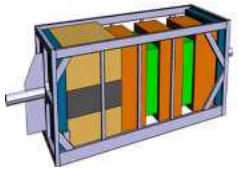
The Hyper-Kamiokande Experiment

J-PARC beamline

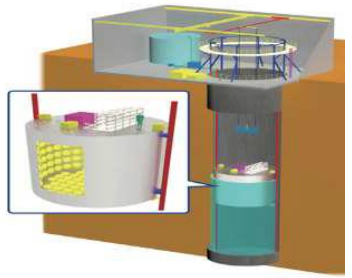
Near detectors



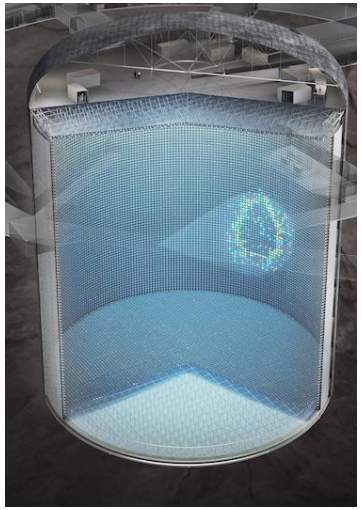




Intermediate water Cherenkov detector

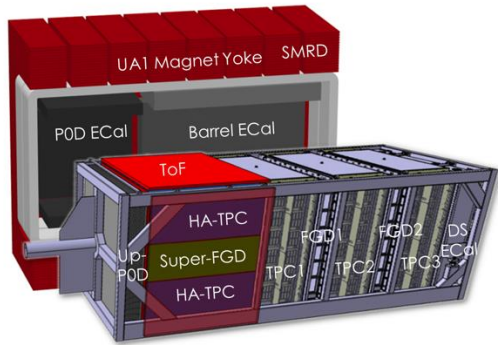


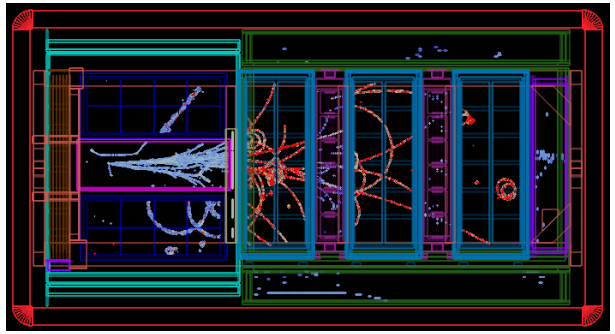
Far detector



280 m ~1 km 295 km

Beamline and near detectors



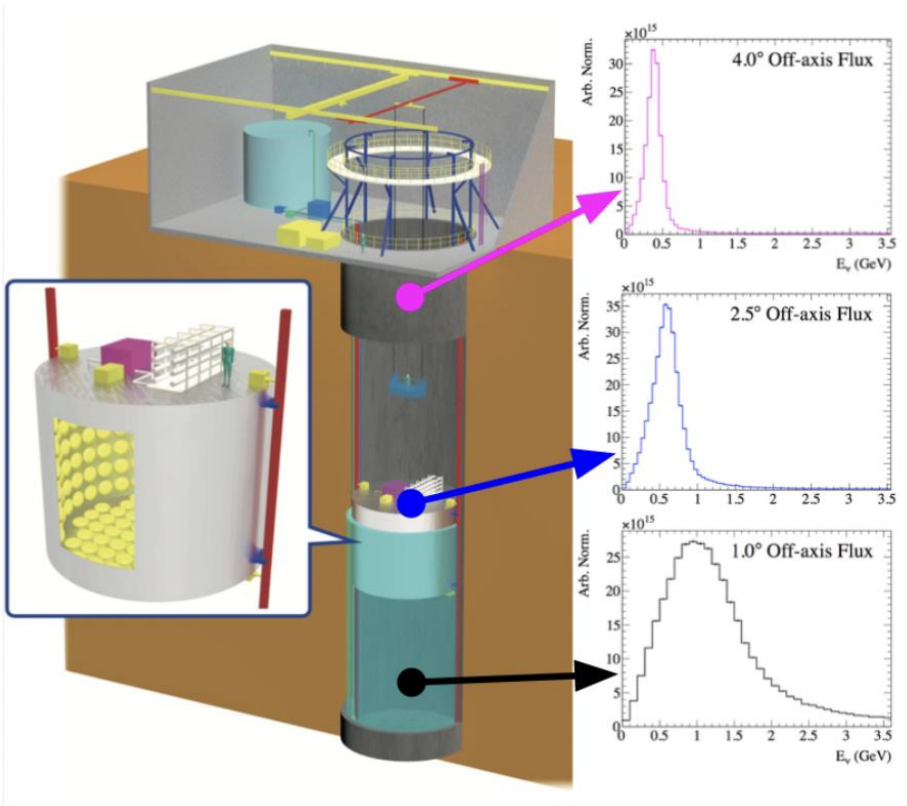


J-PARC beamline: upgraded from 0.75 MW to 1.3 MW.

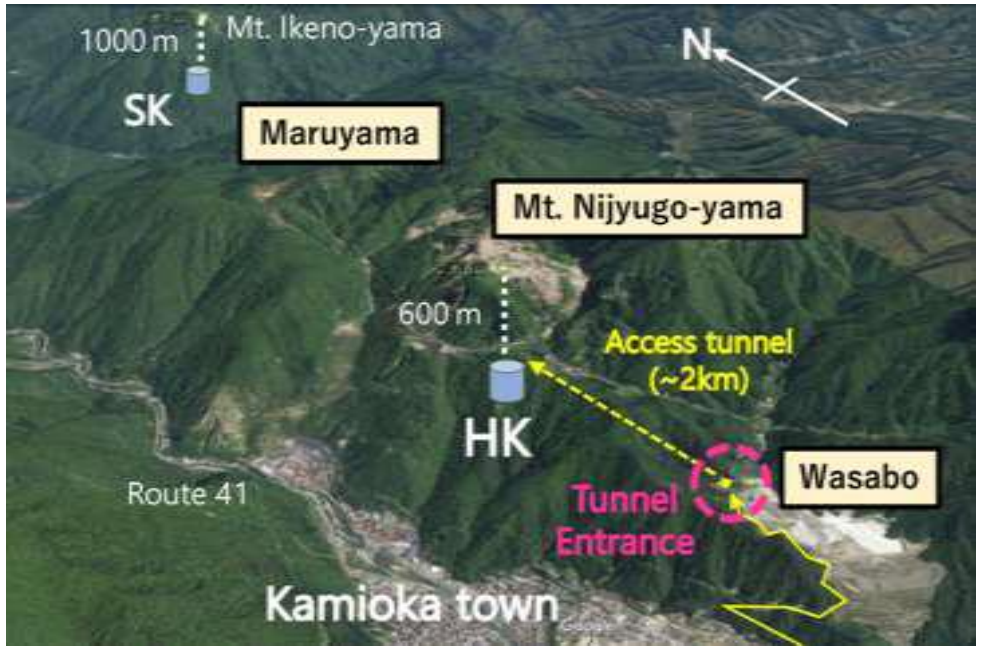
Near detectors: Continued operation of the upgraded T2K near detectors in Hyper-K era.

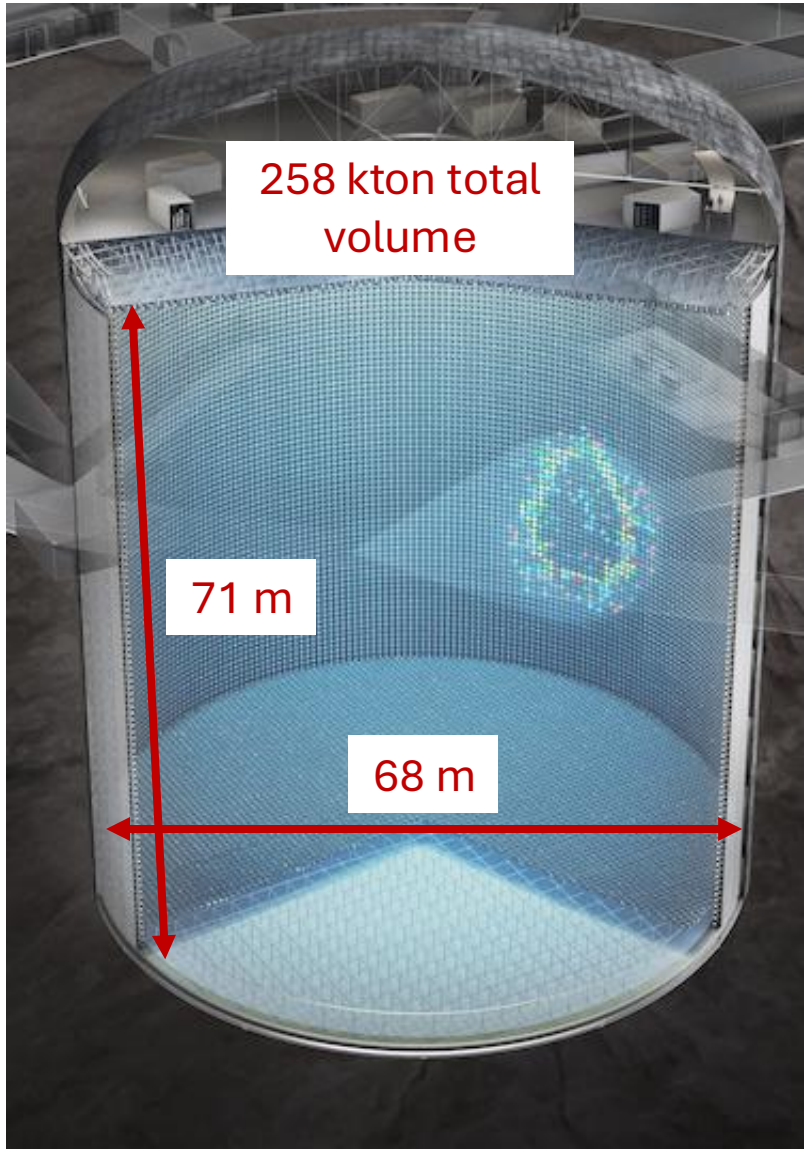
Intermediate Water Cherenkov Detector (IWCD):

- Measurement of the beam at different off-axis angles.
- “monochromatic” energy sample at each off-axis angle.
- Can be weighted and combined to create an arbitrarily shaped neutrino energy spectrum.



Far detector





Water Cherenkov detector:

- Approx. 8 x Super-K volume.
- 20,000 PMTs (50 cm diameter) with 2 x Super-K efficiency.

Hyper-Kamiokande construction

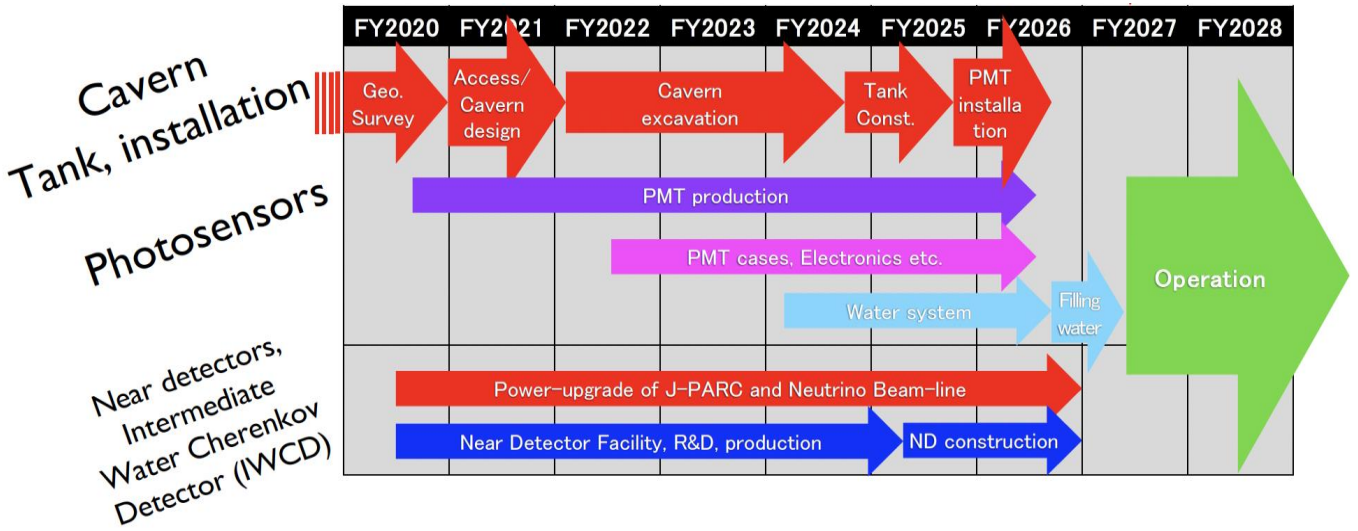
Construction: Started in 2020.
Data-taking: Expected 2027, ***with beam***

2020: Start of construction

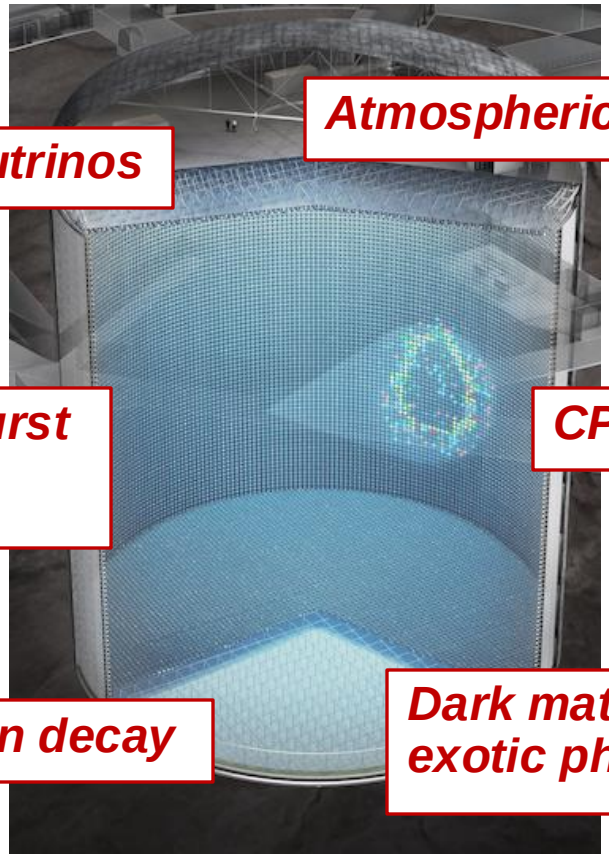
2022: Centre of the dome reached

2023: Dome excavation complete

Cavern excavation will be complete by the end of 2024!



Physics programme



Solar neutrinos

Atmospheric neutrinos

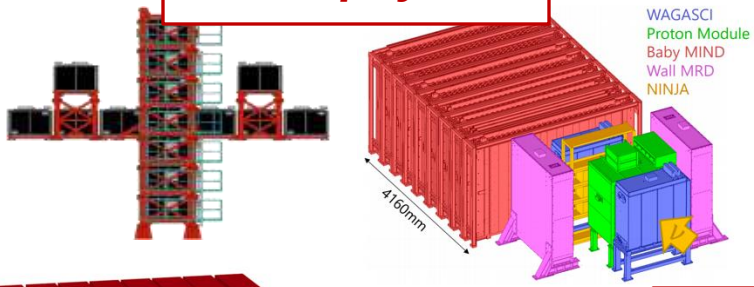
Supernova burst neutrinos

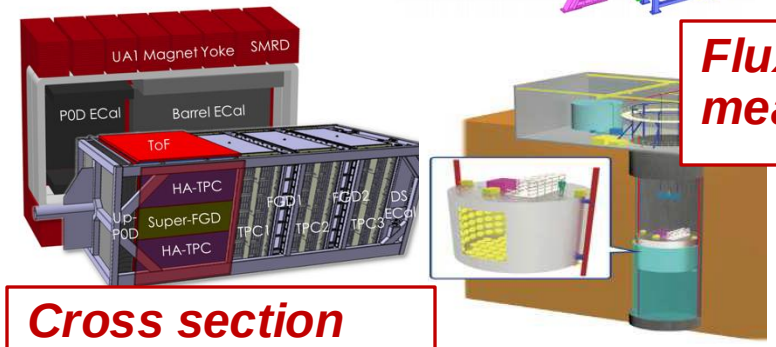
CP violation

Nucleon decay

Dark matter and exotic physics

Exotic physics





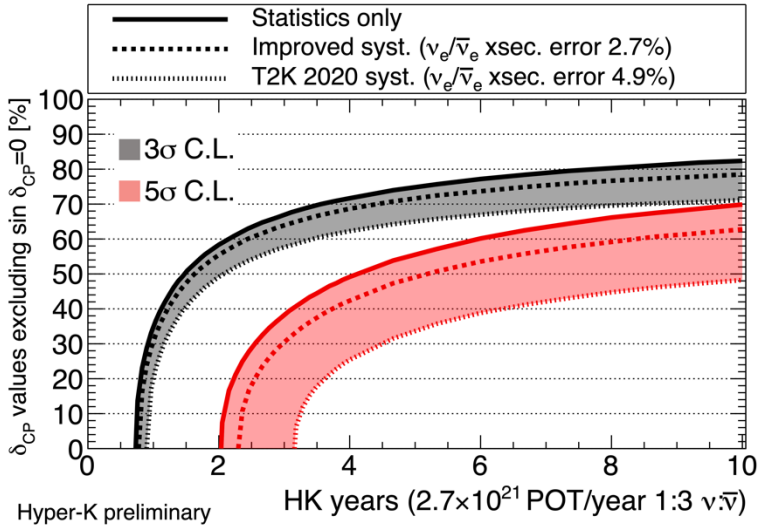
Flux measurements

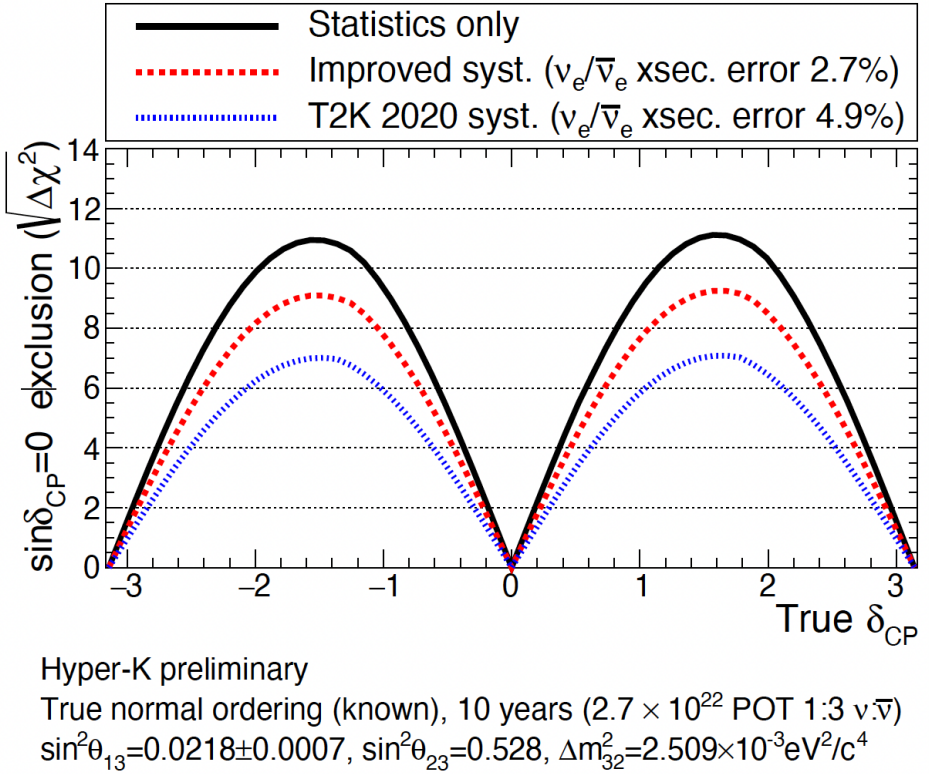
Cross section measurements

Physics: Neutrino oscillations

Precision measurement of neutrino oscillations:

- Discovery of CP violation at $> 5\sigma$ for $> 60\%$ of δ_{CP}.
- 1σ resolution of δ_{CP} in 10 years:
  - $\sim 20°$ for $\delta_{CP} = -90°$
  - $\sim 6°$ for $\delta_{CP} = 0°$
- Reduction of systematic uncertainty has sizable impact.

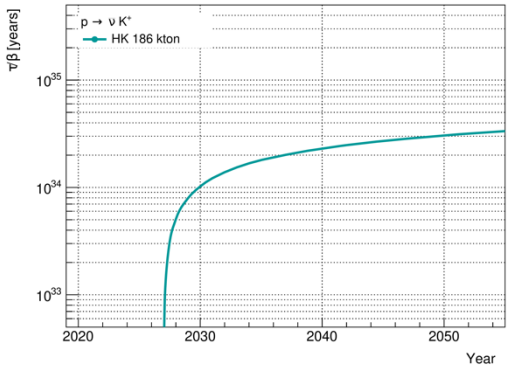




Physics: Proton decay, solar neutrinos

Proton decay:

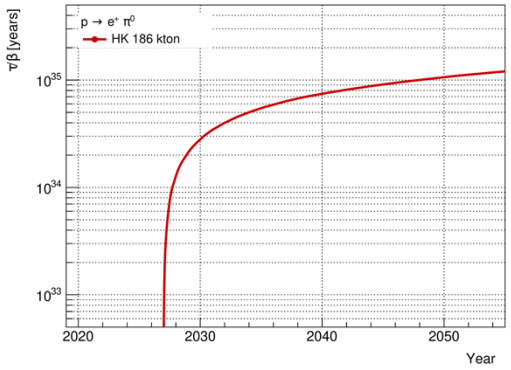
- Proton decay search can be extended by an order of magnitude beyond current limits.



Hyper-K 10 years:

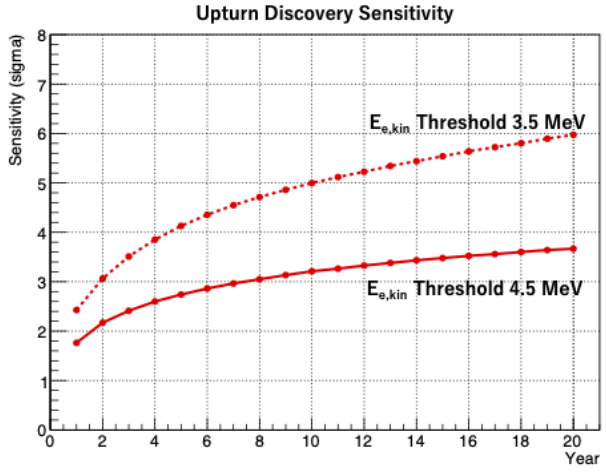
$p \rightarrow e^{+}\pi^{0}$: $\sim 6 \times 10^{34}$ y

$p \rightarrow \nu K^{+}$: $\sim 2 \times 10^{34}$ y



Solar neutrinos:

- ~130 events expected per day ($E_{Th} = 4.5$ MeV)
- Confirm MSW effect by observation of upturn in energy spectrum.



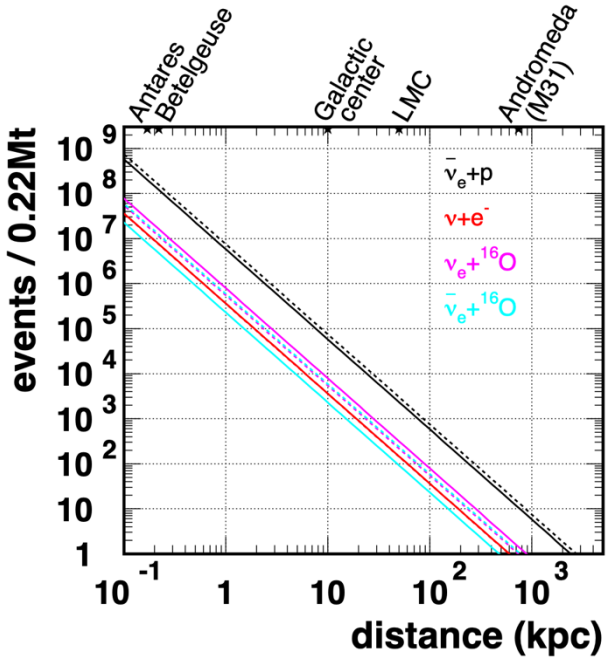
Hyper-K 10 years:

$> 3\sigma$ sensitivity for spectrum upturn ($E_{Th} = 4.5$ MeV)

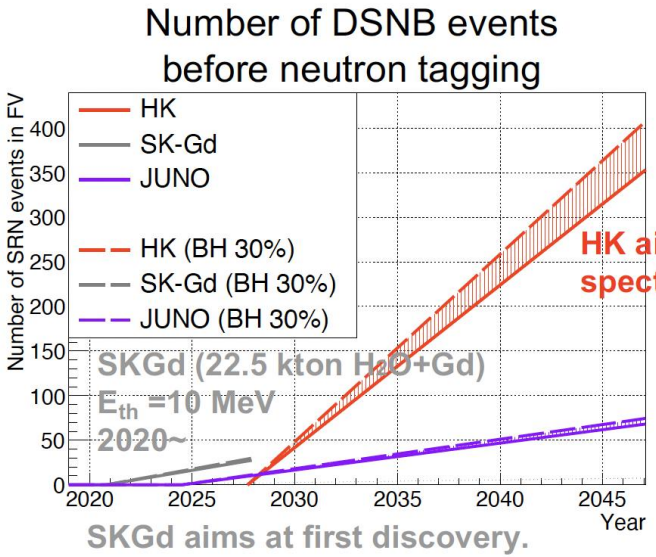
Physics: Neutrino astrophysics

Supernova burst:

- Exceptional statistics due to size of Hyper-K.
- Excellent complementarity with other experiments.
- >70k neutrinos expected for 10 kpc supernova.



Diffuse Supernova Neutrino Background (DSNB):



HK (187 kton H_2O)
E_{th} =16 MeV
2027~

HK aims for precise flux & spectrum measurement.

JUNO (20 kt LS)
E_{th} =12 MeV
2024~

SKGd aims at first discovery.

Hyper-K Europe and UK

~600 persons from 22 countries and growing!

- Project hosts
  - Far detector: University of Tokyo
  - Beam/near detectors: KEK/J-PARC
- UK is second largest member of Hyper-K.
- International leadership roles: International co-spokesperson, six working group conveners, Deputy Technical Coordinator.

Recognised experiment at CERN (RE45)

- Active member of CERN neutrino platform.
- Electronics assembly and testing at CERN.

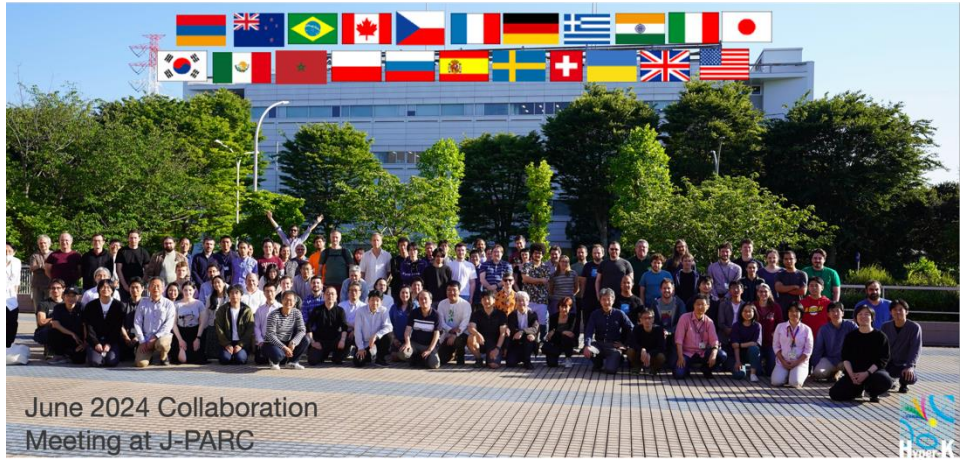
Europe	335 members
Armenia	3
Czech	8
France	50
Germany	1
Greece	4
Italy	46
Poland	45
Russia	21
Spain	45
Sweden	5
Switzerland	14
Ukraine	2
UK	91

Asia	164 members
India	9
Korea	19
Japan	136

Oceania	9 members
Australia	9

Americas	67 members
Brazil	3
Canada	43
Mexico	11
USA	10

Africa	11 members
Morocco	11

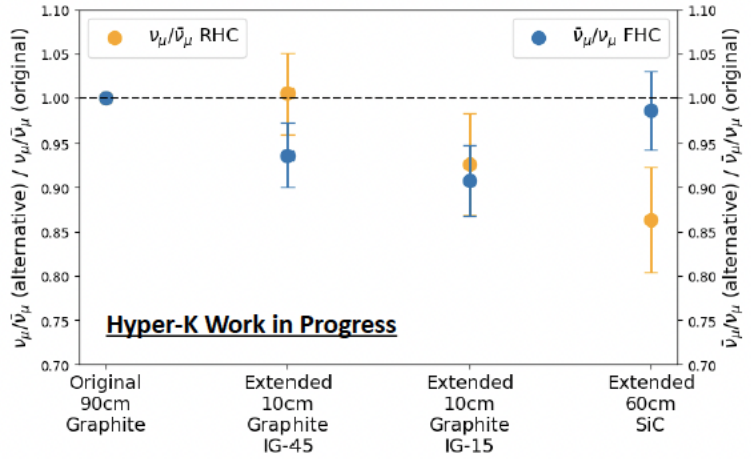


June 2024 Collaboration Meeting at J-PARC

Hyper-K UK: Beamline and outer detector

Beamline:

- Beam targets and windows for high-powered operations.
- Upgraded target designs to increase flux and reduce wrong-sign contamination.
- Simulation of hadron production from target.



Double ratio of wrong-sign contamination (target alternative/original) in neutrino flux for various target lengths and densities.

Figure from L. Machado, Neutrino Beam Simulations for the Hyper-Kamiokande experiment and target alternatives, XXXI International Conference on Neutrino Physics and Astrophysics, 2024

Outer detector:

- Essential veto for background particles.
- Selection and validation of PMTs for OD.
- Design of outer detector electronics.
- Design, construction, installation and commissioning.

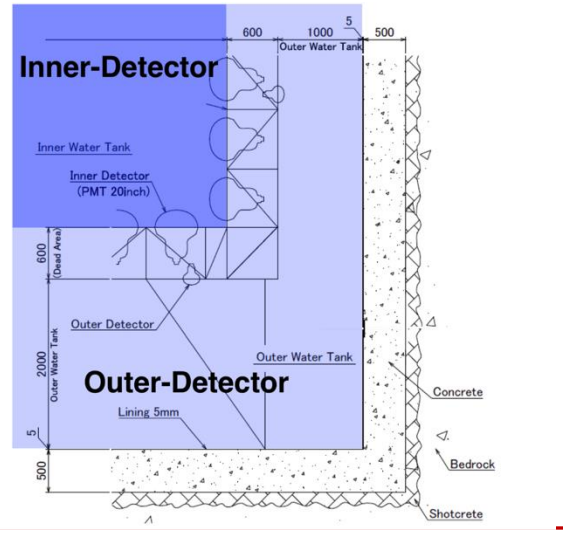


Figure from https://www-sk.icrr.u-tokyo.ac.jp/en/hk/about/detector/

Hyper-K UK: DAQ and calibration

DAQ:

- Software-based DAQ, trigger and monitoring systems using “off the shelf” hardware.
- Sufficient buffer space in case of supernova.
- Simple trigger for E > 10 MeV events + sophisticated low energy triggers.
- Fault tolerant, robust and reliable.

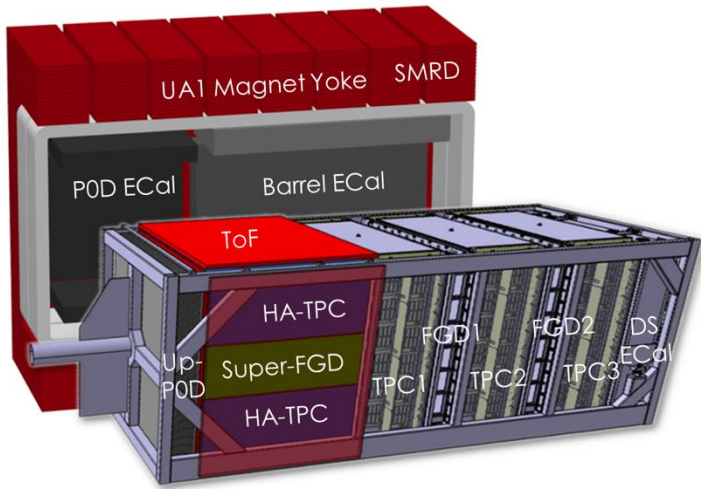
UK test stand and participation in electronics tests at CERN by end of 2024.

Calibration:

- Optical calibration systems to make position/time dependent measurements of
  - water absorption/scattering
  - PMT timing
  - PMT gain.
- Light injection via bare optical fibre, wide angle diffuser or collimator.
- LED pulser board allows tuning of light intensity via custom software.

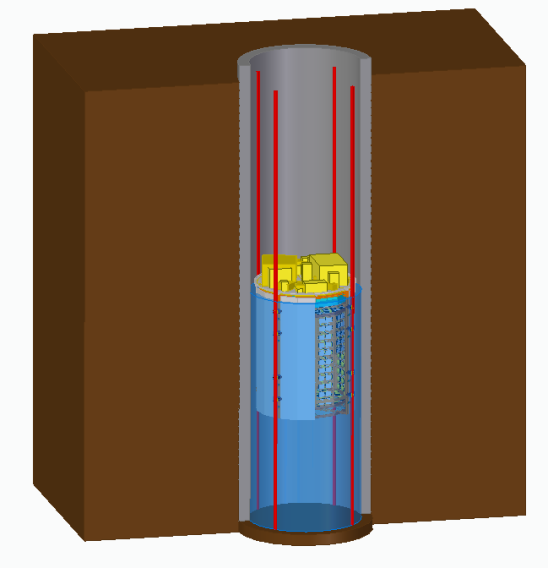
Long-term deployment tests in Super-K.

Hyper-K UK: Near detectors and IWCD



ND280:

- T2K's off-axis near detector at 280 m.
- Upgrade completed - first data this year!
- Increased efficiency for high-angle and low momentum tracks.
- Ongoing UK support for operations and analyses.



IWCD:

- New detector around 1 km from target.
- UK providing DAQ and light injection systems.
- Leading contributions to analysis and software development.

Hyper-K UK: Physics, software and computing

Software and computing:

UK leading development of:

- Simulation software for far and intermediate detectors.
- Oscillation analysis framework (MaCh3)
- Distributed computing model.

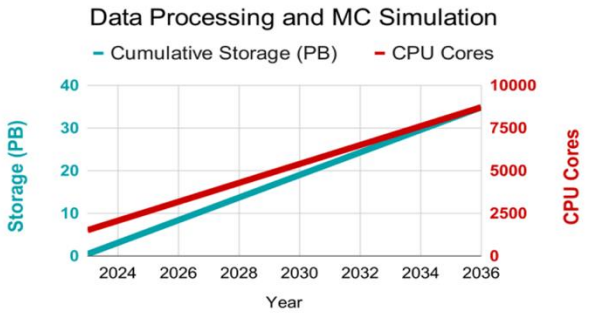


Figure 1: The total computing forecasts, covering all the Hyper-K detectors, considering both data and MC needs, and for all signal, background and control/calibration samples. Note that the storage estimate is per replica.

S. King, EPJ Web of Conferences 295, 04016 (2024), CHEP 2023.

Physics:

- Sensitivity studies for CP-violation and oscillation parameters.
- Proton decay and BSM physics
- Supernova neutrinos, diffuse supernova neutrino background and astrophysics.
- Atmospheric neutrinos.
- Measurements of $\sigma(\nu_e)/\sigma(\nu_\mu)$ and $\sigma(\bar{\nu}_e)/\sigma(\bar{\nu}_\mu)$ using the intermediate detector.
- (Measurements using near detector)

Hyper-K UK: Future

Next 5 years:

- Construction will complete in 2027.
- UK members will be on site for installation, commissioning and operation of key systems.
- UK will maintain its systems during data-taking operations.
- UK will maintain leading roles in software, physics and computing to ensure readiness for “first physics”.

First physics results!

Next 5 -10 years:

- Build upon first physics results:
  - Mass ordering: $3.8 - 6.2\sigma$ depending on $\sin^2\theta_{23}$
  - CP violation: 5σ discovery, $> 60\%$
  - Proton decay: $p \rightarrow e^+\pi^0$: 6×10^{34} y
  - $> 3\sigma$ sensitivity for the solar neutrino spectrum up-turn
  - ~70k events @10 kpc supernova
  - ~4 events/year diffuse supernova neutrino background
- Improved systematic uncertainties.
- Near detector upgrade
- Studies for future improvements to the detectors its beamline and detectors.

Exciting physics results expected in the next 10 years in addition to CP-violation.

Conclusions

- Hyper-K is currently under construction in Japan.
- Data taking (with beam) is expected to start in 2027.
- Extremely rich physics programme:
  - Neutrino oscillations: CP violation, precision measurements of mixing parameters, mass ordering.
  - Neutrino astrophysics: Supernova bursts, solar neutrinos, DSNB.
  - Proton decay limits improved by a factor of 10.
  - Atmospheric neutrino measurements
- Significant UK involvement in the project, established international leadership.
- Leading involvement from the UK in physics, software and computing.
- Opportunity to further develop the experiment, beamline and detectors.

Exciting, important results expected in the coming decade.