Status of the Hyper-Kamiokande Experiment

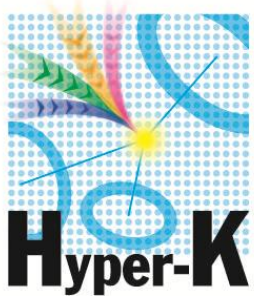
Menai Lamers James

On behalf of the Hyper-Kamiokande collaboration

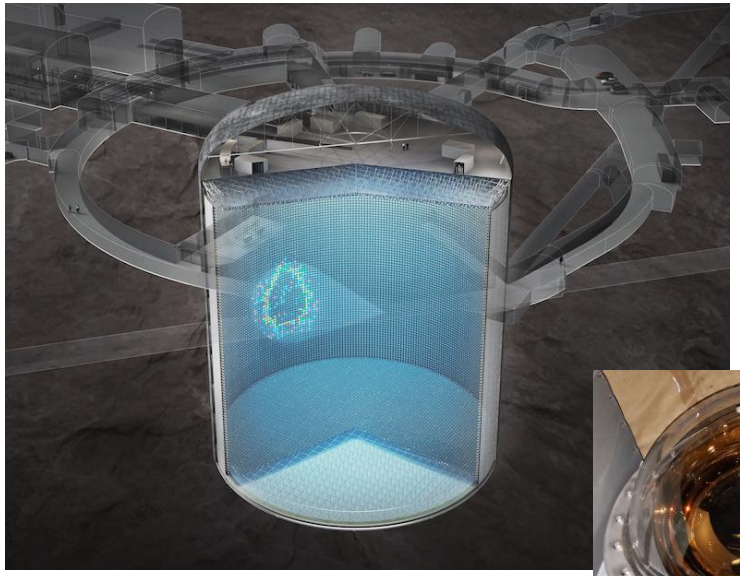
21st Rencontres du Vietnam, Neutrino Physics

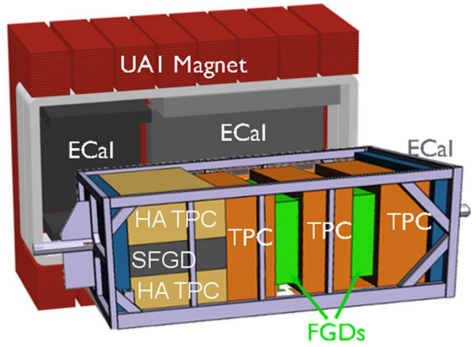
21-25 July 2025

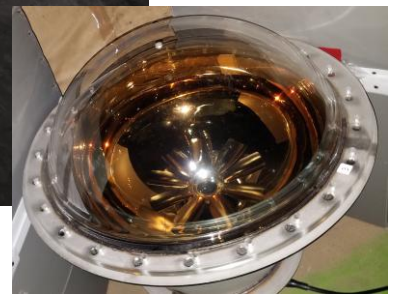
UNIVERSITY OF WARWICK

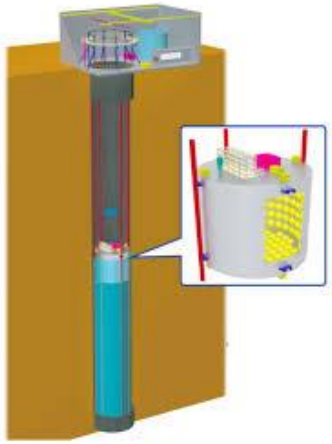


Experiment Overview





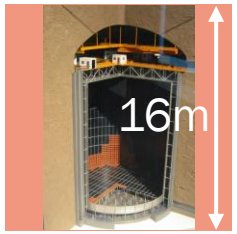


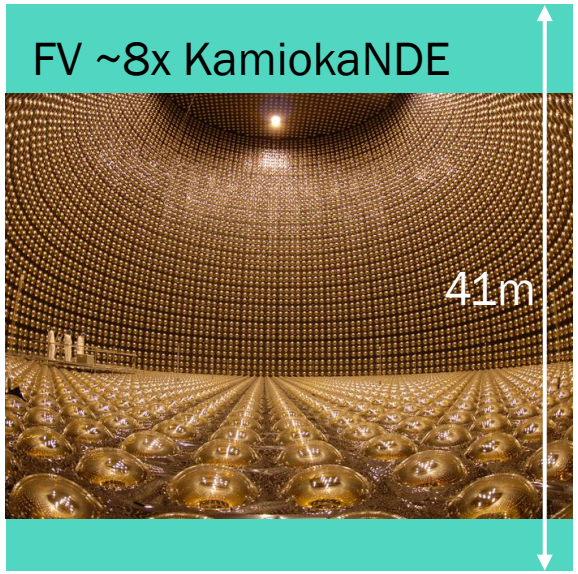


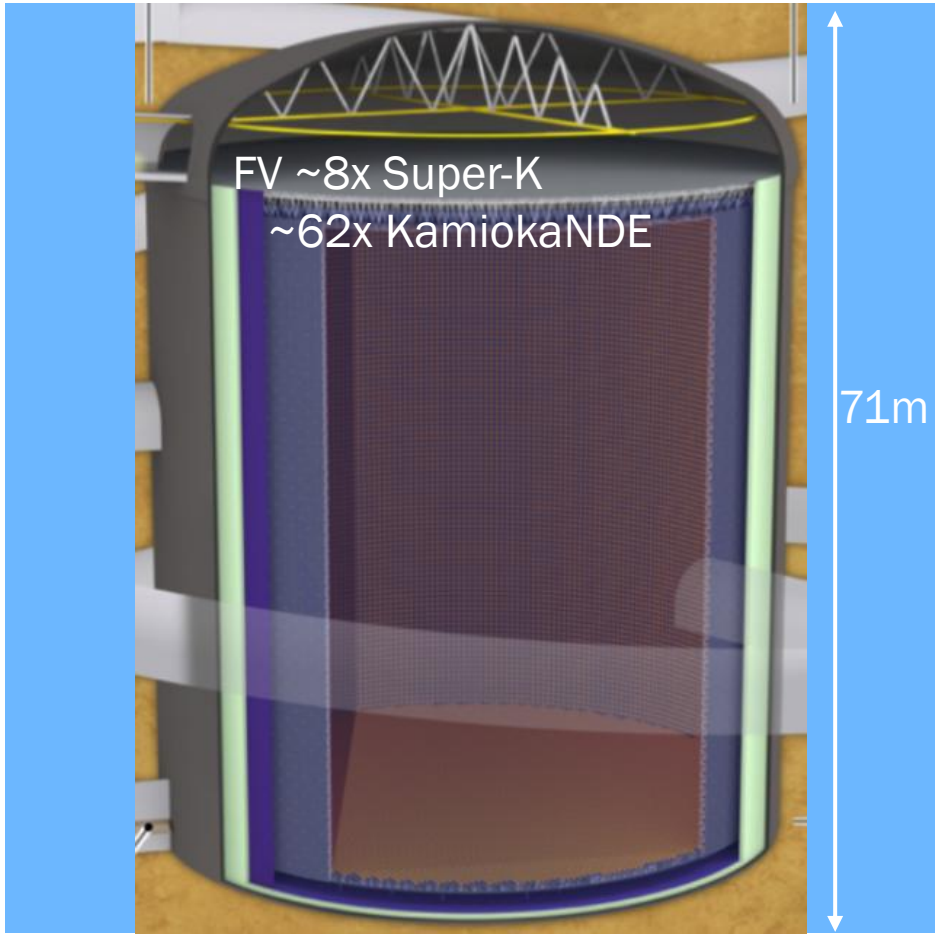
- Hyper-Kamiokande (Hyper-K) is the next generation water Cherenkov neutrino experiment.
- Building upon the successes of the Super-Kamiokande and T2K experiments.
- Increased detector volume and improved newly designed high-sensitivity photosensors.
- Higher intensity neutrino beam produced by J-PARC accelerator.

Predecessors

- KamiokaNDE: 1983-96
- Super-Kamiokande: 1996-
- Hyper-Kamiokande: 2028-





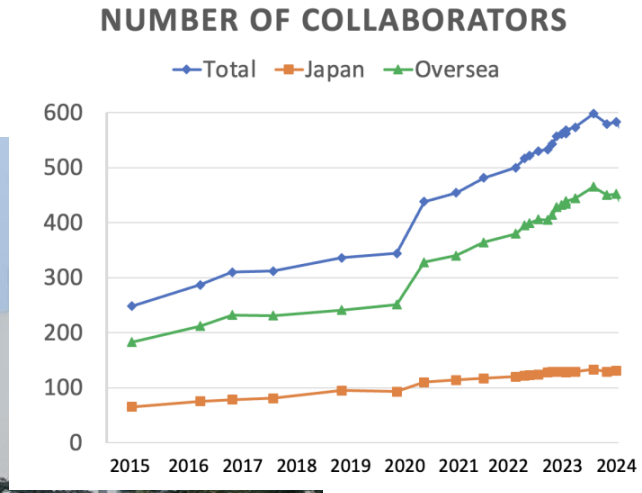


Similar height to Lady Buddha, Linh Ung Pagoda, 67 m (Vietnam).

Taller than the Leaning Tower of Pisa, 57 m (Italy) and the Statue of Liberty, 46 m (USA).

Collaboration

- Growing collaboration.
- 22 countries, 106 institutes, ~650 members (2025).



Physics Goals

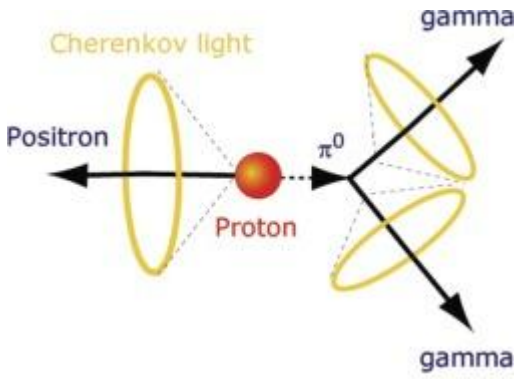
- Diverse physics program possible with a variety of detectable sources.

Supernova Properties

Supernova burst detection
Diffuse supernova background

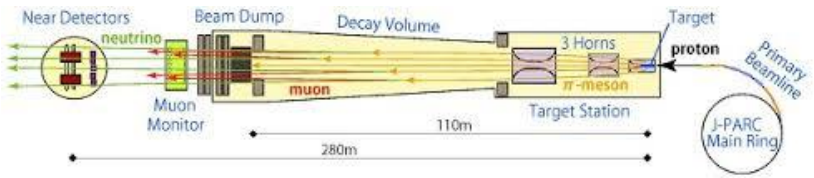
Nucleon Decay

Searches for proton decay



Oscillation Analysis

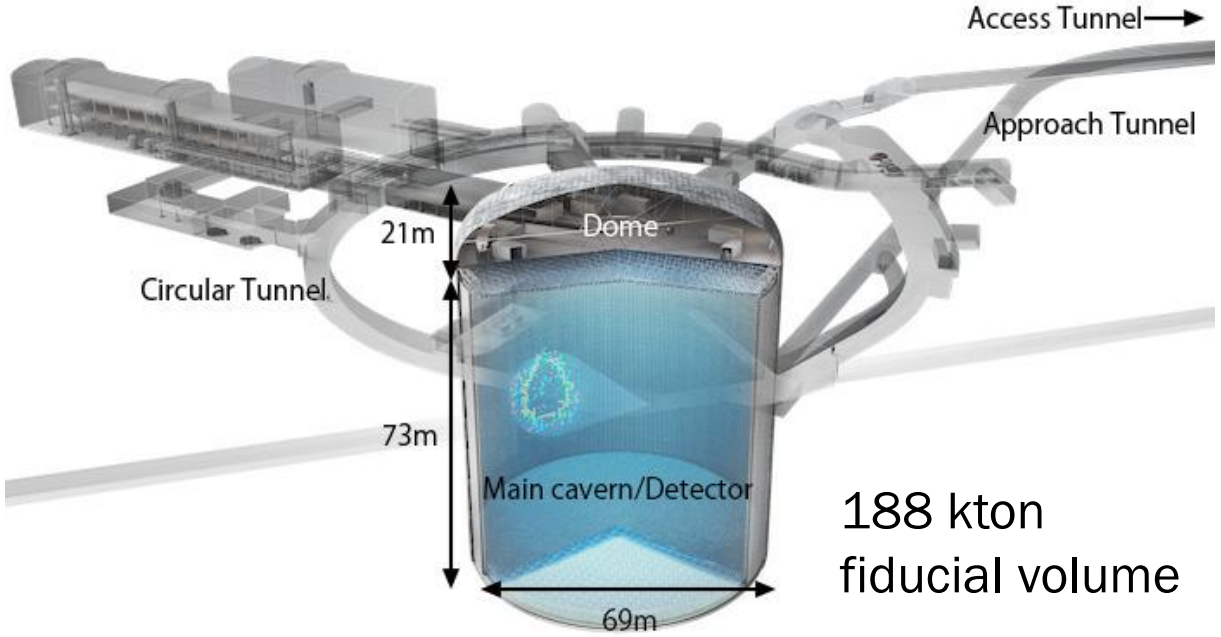
CP symmetry
Mass ordering
Measurements of θ_{23}



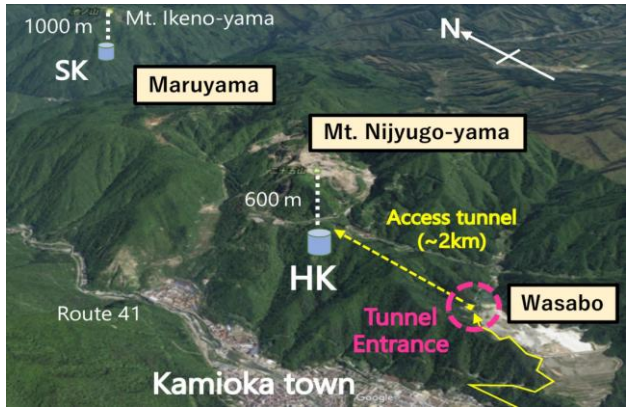
Experimental Setup

- Far Detector located on West central coast of Japan, near the Super-Kamiokande site.
- Intermediate Water Cherenkov Detector (IWCD) and ND280 near detectors located on the East central coast of Japan near J-PARC.
- ND280 is 280 m downstream of the beam. IWCD is 850 m away.

Far detector



188 kton fiducial volume



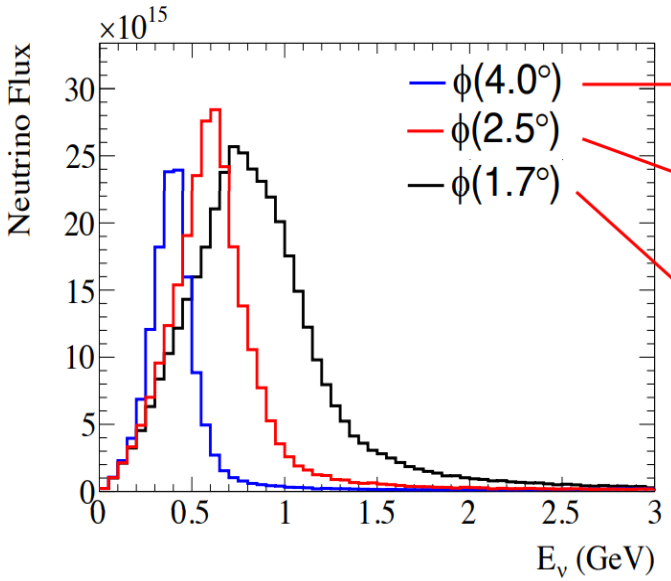
- Large water Cherenkov detector.
  - Similar conceptually to Super-Kamiokande (Super-K) -> tried and tested methods.
- Fiducial volume ~8x Super-K.
  - Larger size = more statistics.
- ~20,000 50 cm PMTs.
- ~800 multi PMTs.

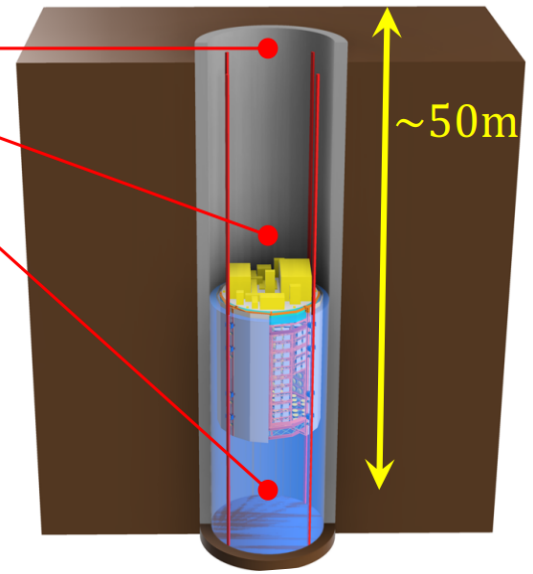
  } Located throughout the Inner Detector.
- ~3600 3” PMTs in the Outer Detector.
- Pure water target cheap relative to other targets.
- Located 8 km away from Super-K.
- Rock overburden of 600 m.

Intermediate Water Cherenkov Detector

UNIVERSITY OF WARWICK

- New near detector located ~850m downstream of the beam.
- Diameter of 8.8 m and instrumented with mPMTs.
- Aims to reduce systematic uncertainties.
  - Detector moves up and down to sample from different beam angles -> broader energy spectrum.
  - Greater constraints due to extra degree of freedom from broader energy spectrum.
  - Water target and full angular acceptance.
  - Measurements of $\sigma(\nu_e)/\ \sigma(\nu_\mu)$ and $\sigma(\bar{\nu}_e)/\ \sigma(\bar{\nu}_\mu)$ to improve sensitivity to δ_{CP}.

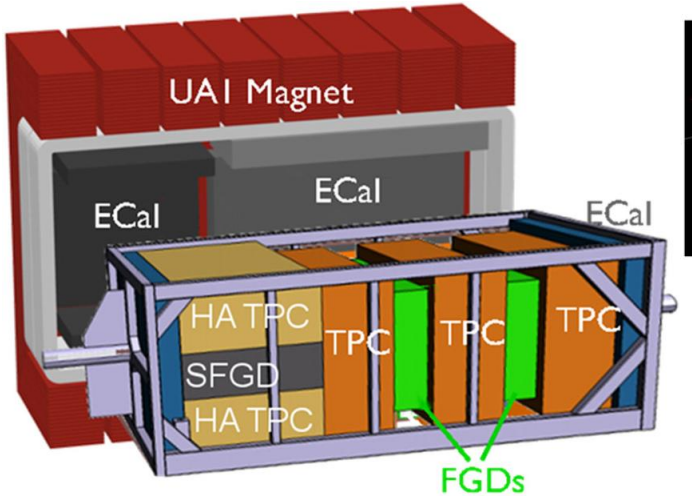


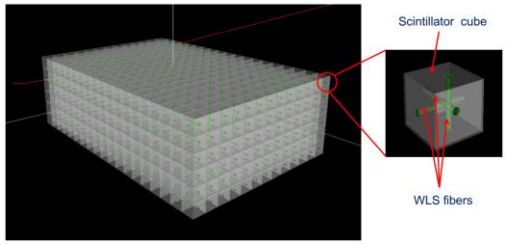


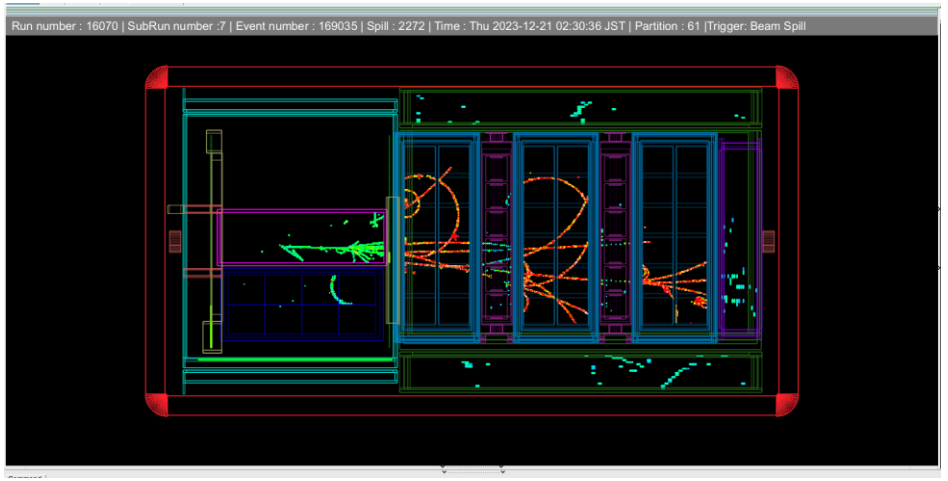
More details in F. Nova's talk!

ND280 Near Detectors

- Located 280 m downstream of the beam.
- Recent ND280 upgrade completed in 2024.
  - New Super-FGD, High-Angle TPCs and TOF.
  - Improved angular acceptance and decreased hadronic energy threshold.
- Key to controlling systematics of flux and cross section parameters.
- T2K demonstrated a reduction of these systematics to 3-4%.
- Crucial for oscillation analysis results as statistical uncertainty of ν_e appearance reaches ~3% in 10 years.



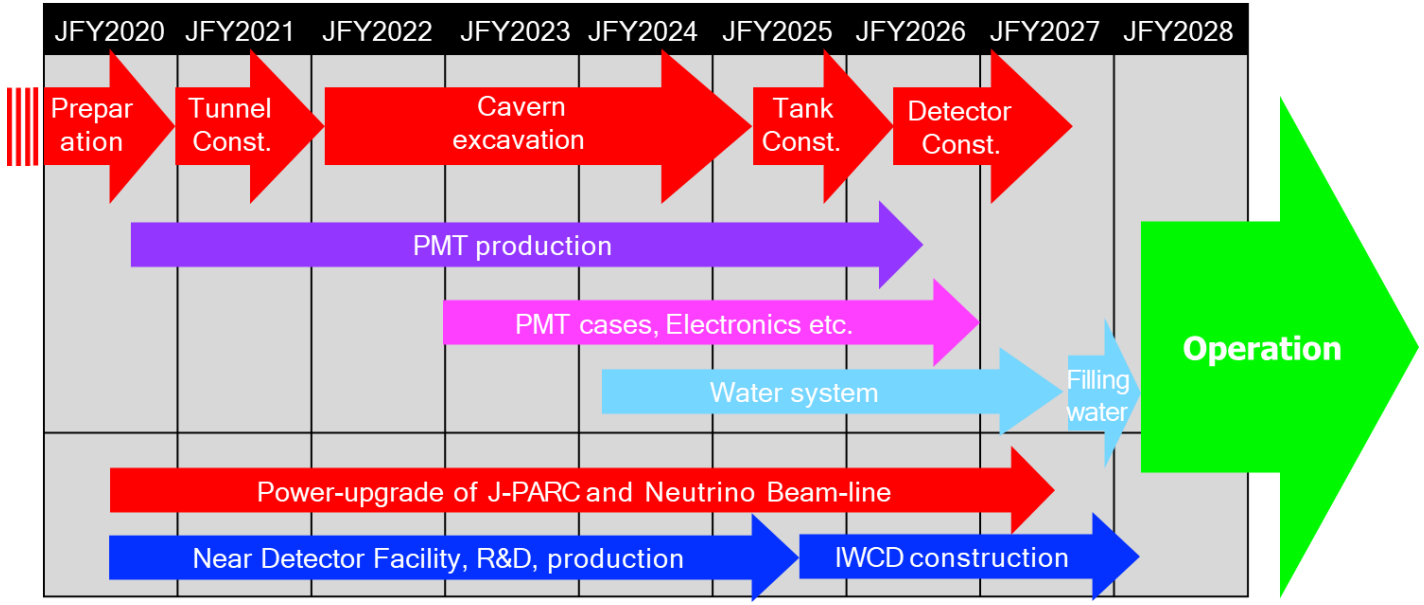




Beamline Upgrades

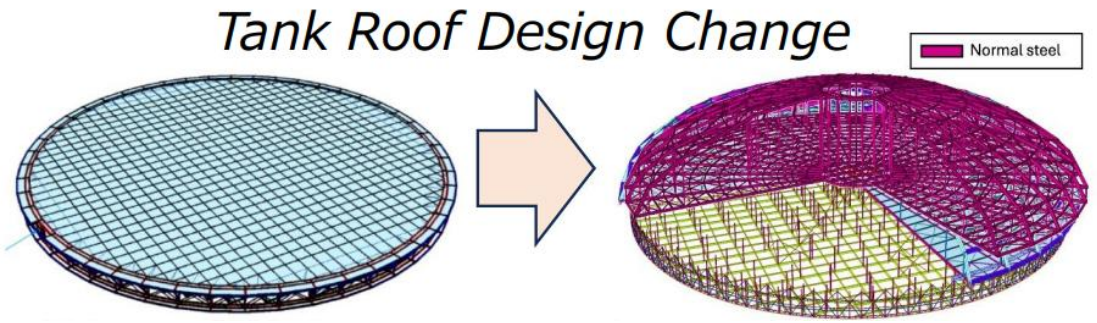
- Continuous beam power at 1.3 MW expected by start of data taking.
  - Decrease cycle time from 1.36 to 1.16 s.
  - Increase protons per pulse from 2.6 x 10^{14} to 3.3 x 10^{14} by upgrading RF system.
  - Reducing beam loss with optics improvements.
- Already exceeded 900 kW in 2024! T2K ran stably at 800 kW in 2024.
- Upgrades to neutrino beamline, improved power supply of horns.
- 250 -> 320 kA.
  - Neutrino flux increases by 10%.
  - Reduces wrong-sign neutrino contamination by 5-10%.

Timeline



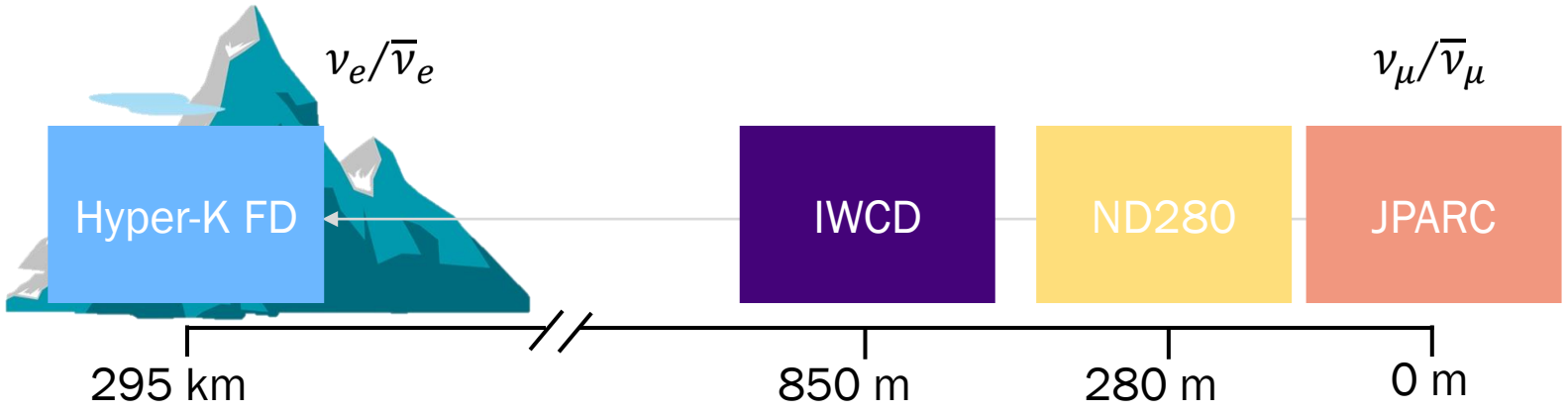
- Data taking will begin in 2028.
- Cavern Excavation – additional support added for safety -> cavern excavation extended by 6 months.
- Tank design change – changes to the roof design -> construction period extended by 5 months.

- Original design – roof plate + PMT support structure made from stainless steel.
- New design – Dome-shape structure made from inexpensive iron. Roof plate and PMT-structure below (stainless steel) are simplified.



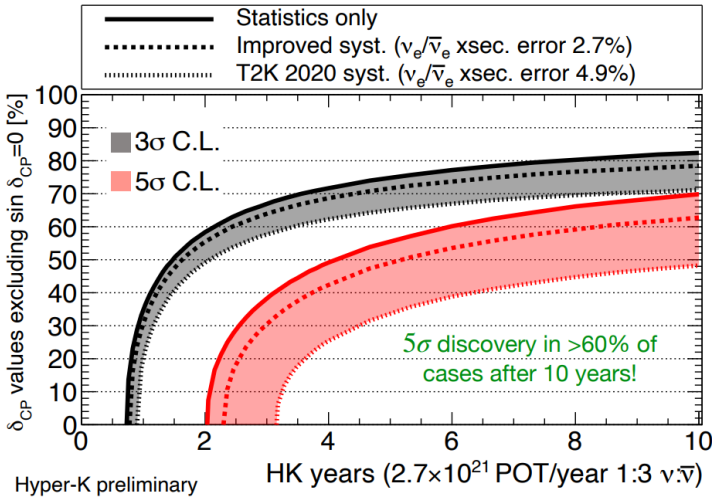
Long Baseline Oscillations

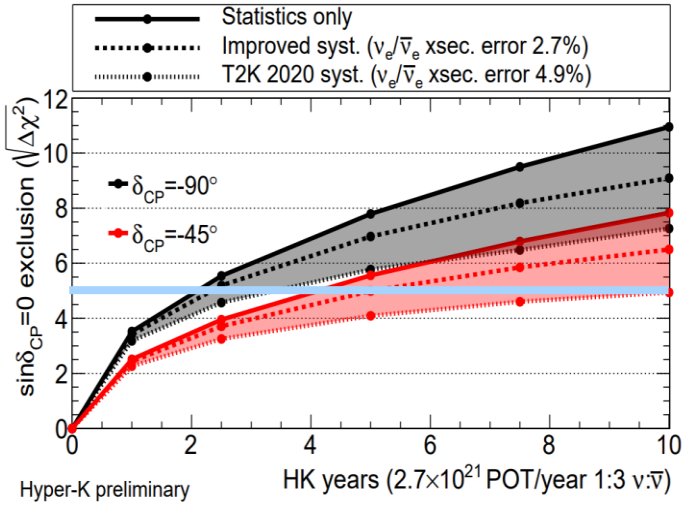
- Similar setup and same baseline as T2K.
- Analysis is derived from T2K work but scaled to Hyper-K statistics.
- Improved systematics due to better constraints expected from the ND280 upgrade and IWCD.
- 1:3 neutrino to antineutrino beam operation assumed.



Long Baseline Oscillations

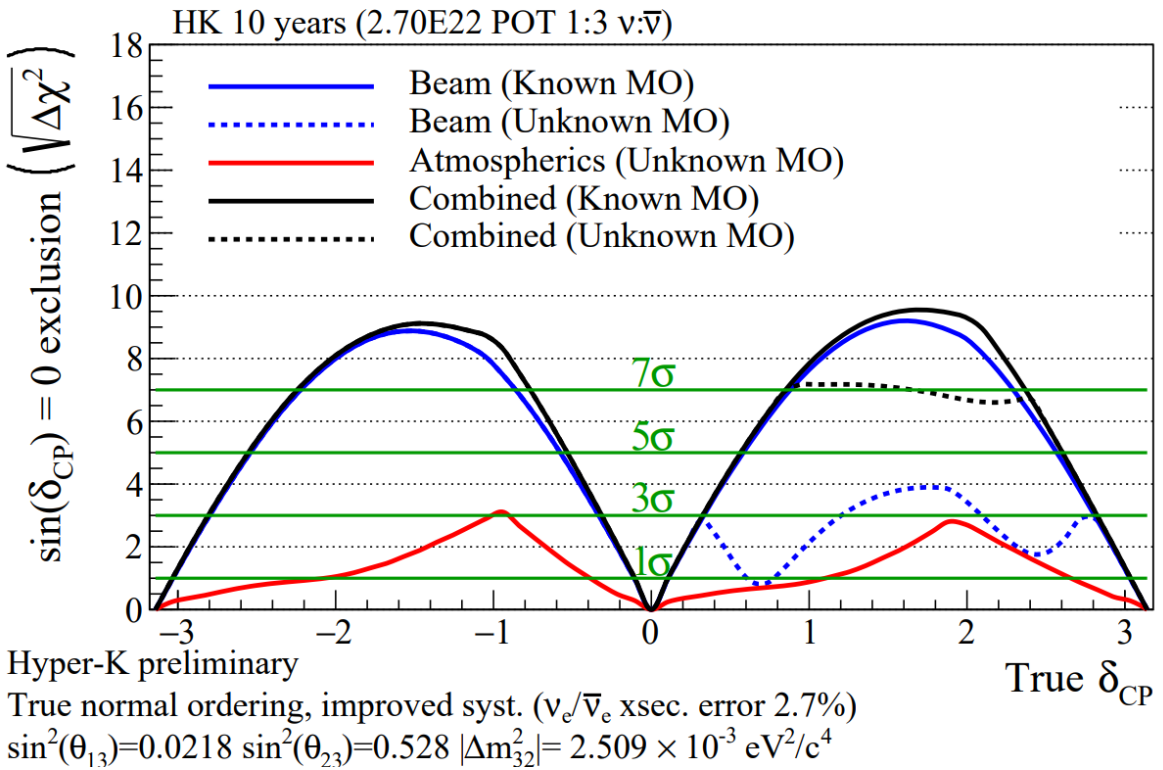
- If the mass ordering (MO) is known and improved systematics used, >60% of true δ_{CP} will achieve 5σ sensitivity after 10 years of operation.
- 5σ possible in less than 5 years if CP violation is maximal and mass ordering is known.
- Sensitivity paper available at https://arxiv.org/abs/2505.15019





5σ

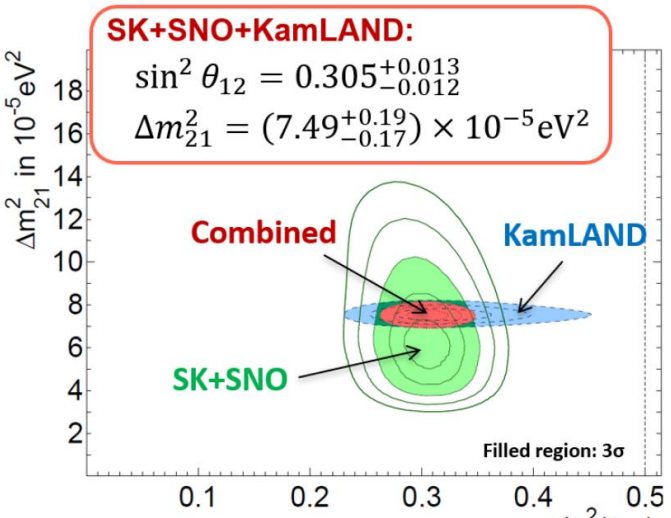
Atmospheric + Long Baseline Oscillations



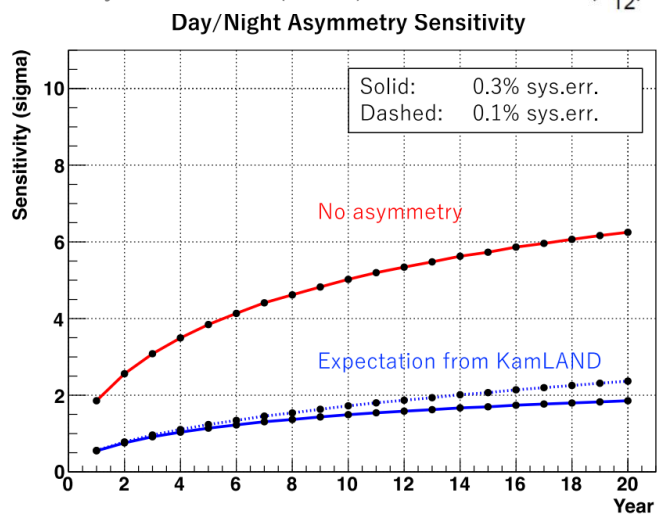
- Long baseline only fit – if MO unknown, degraded performance in degenerate regions.
- Atmospheric neutrino samples – sensitive to MO -> matter effects.
- MO known -> increased δ_{CP} sensitivity.
- Large improvement in δ_{CP} measurement, if MO is not known, with joint atmospheric + beam fit.

Solar Neutrinos Day/Night Asymmetry

- Discrepancy of 1.5 σ exists between solar and reactor data on Δm^2_{21}.
- Test this at Hyper-K by comparing ν_e and $\overline{\nu}_e$ oscillations.
- ~2σ sensitivity to day/night asymmetry after 20 years.
- Can reject no day/night asymmetry to >5σ after 10 years.
- New physics needed to explain the discrepancy if real.

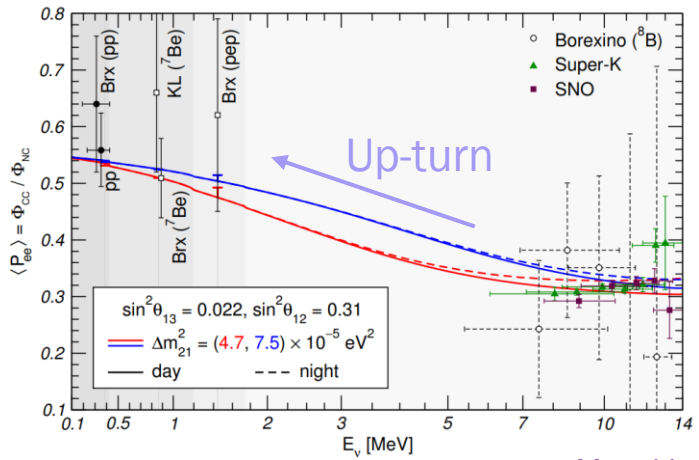


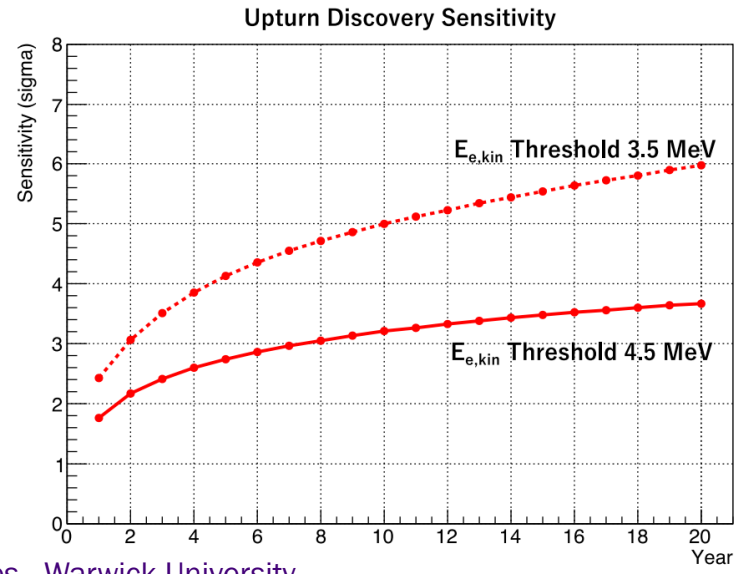
SK Collab., Phys.Rev.D 109 (2024) 9, 092001



Solar Neutrinos – “Up-turn”

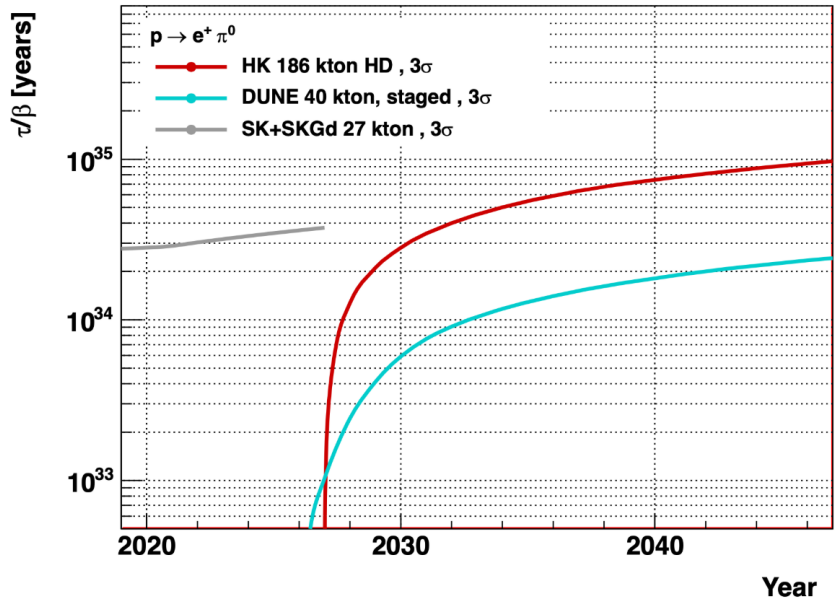
- Measure the spectrum “up-turn” of P($\nu_e \rightarrow \nu_e$) caused by the MSW effect.
- “Up-turn” energy region represents transition between vacuum and matter-dominated oscillations.
- Probe for ordinary oscillation model to more exotic ones.
- 3 - 5σ sensitivity after 10 years.

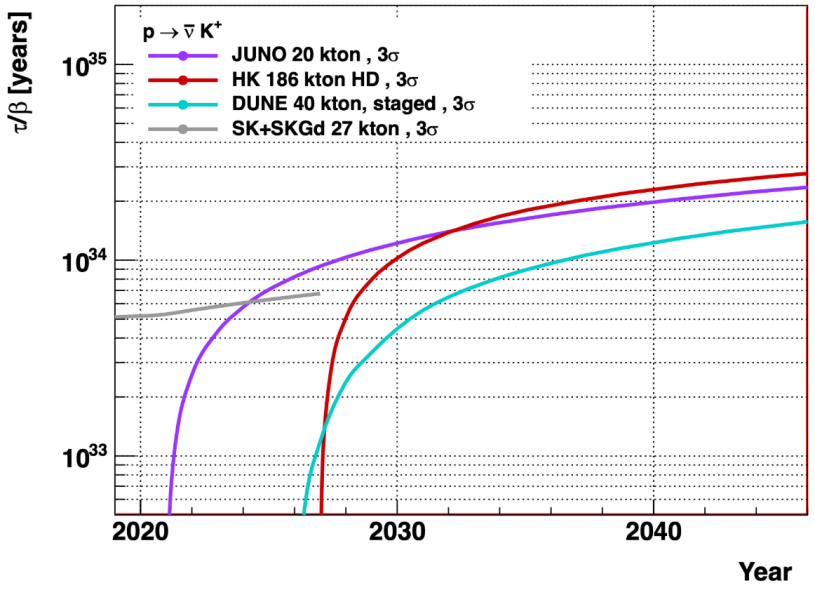




Nucleon Decay

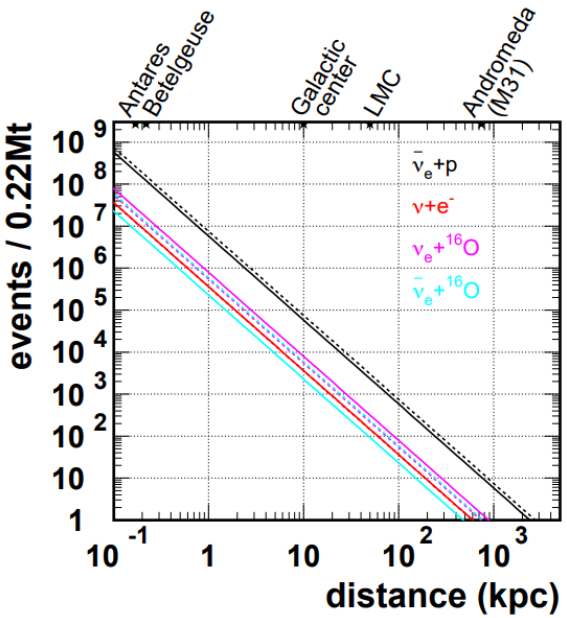
- Nucleon decay predicted in many grand unifying theories.
- Large mass, and free proton in H_2O of Hyper-K aid analysis.
- Hyper-K will probably produce world-leading sensitivity on proton decay for two channels, $p \rightarrow e^+\pi^0$, $p \rightarrow \bar{\nu}K^+$.

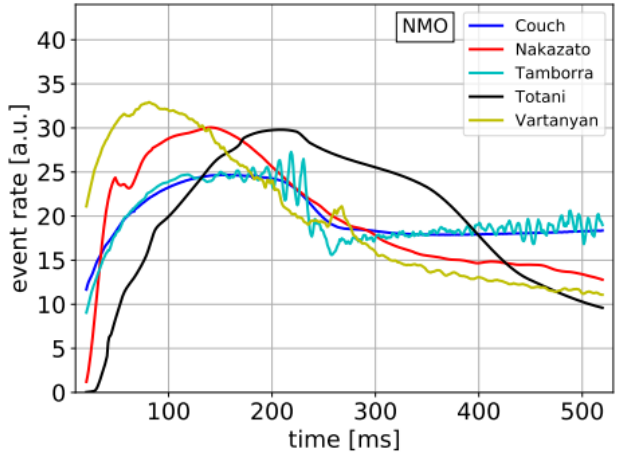


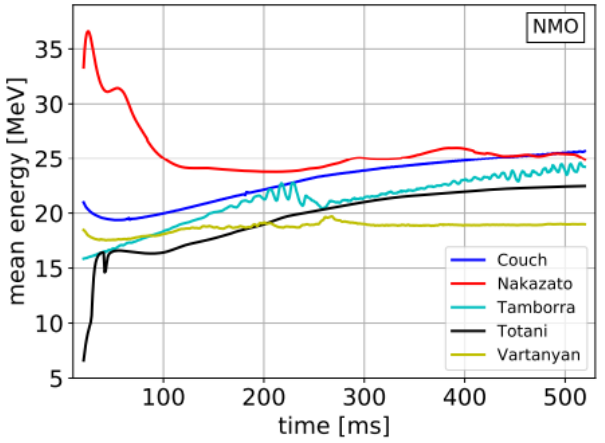


Supernova Burst Neutrinos

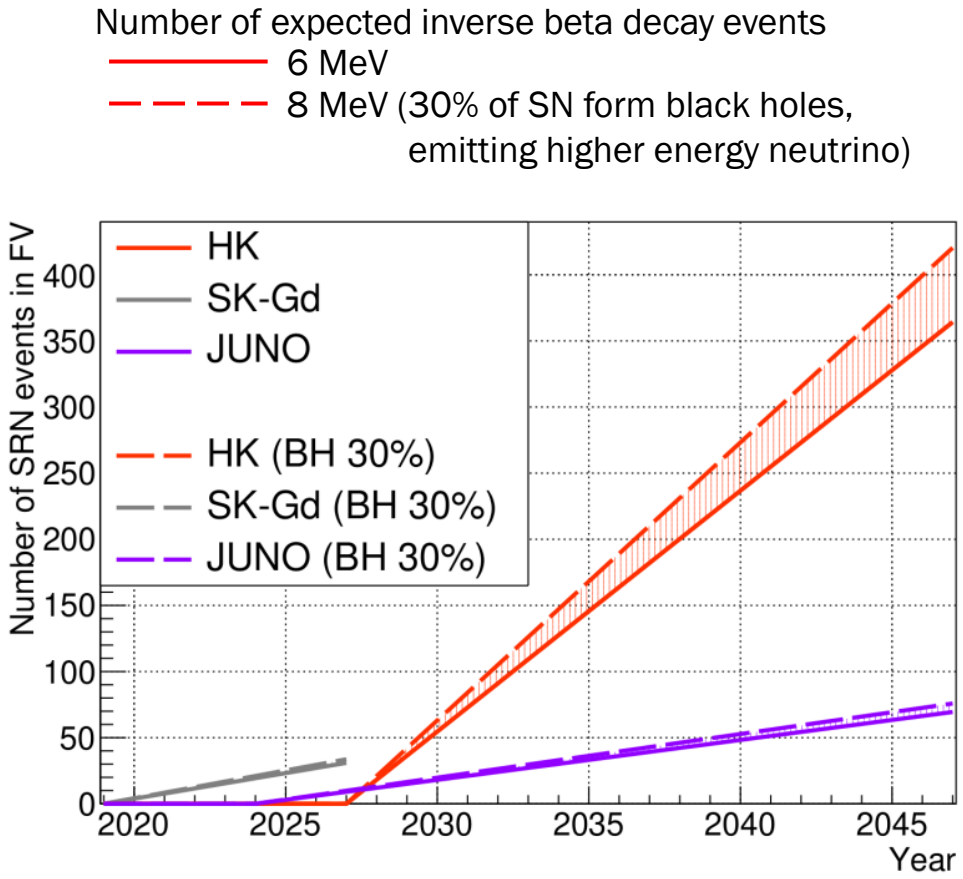
- For a 10 kpc supernova burst we would expect ~70,000 events in a few tens of seconds.
- For SN1987a type distance we would expect 2-3k.
- Neutrinos can help distinguish models from the rate and energy variation with time.
- Hyper-K benefits from direction reconstruction -> 1.3˚ directional pointing for telescope use.
- Neutrino burst occurs before explosion -> pre-supernova alert.
- Continuous specialised SN trigger.





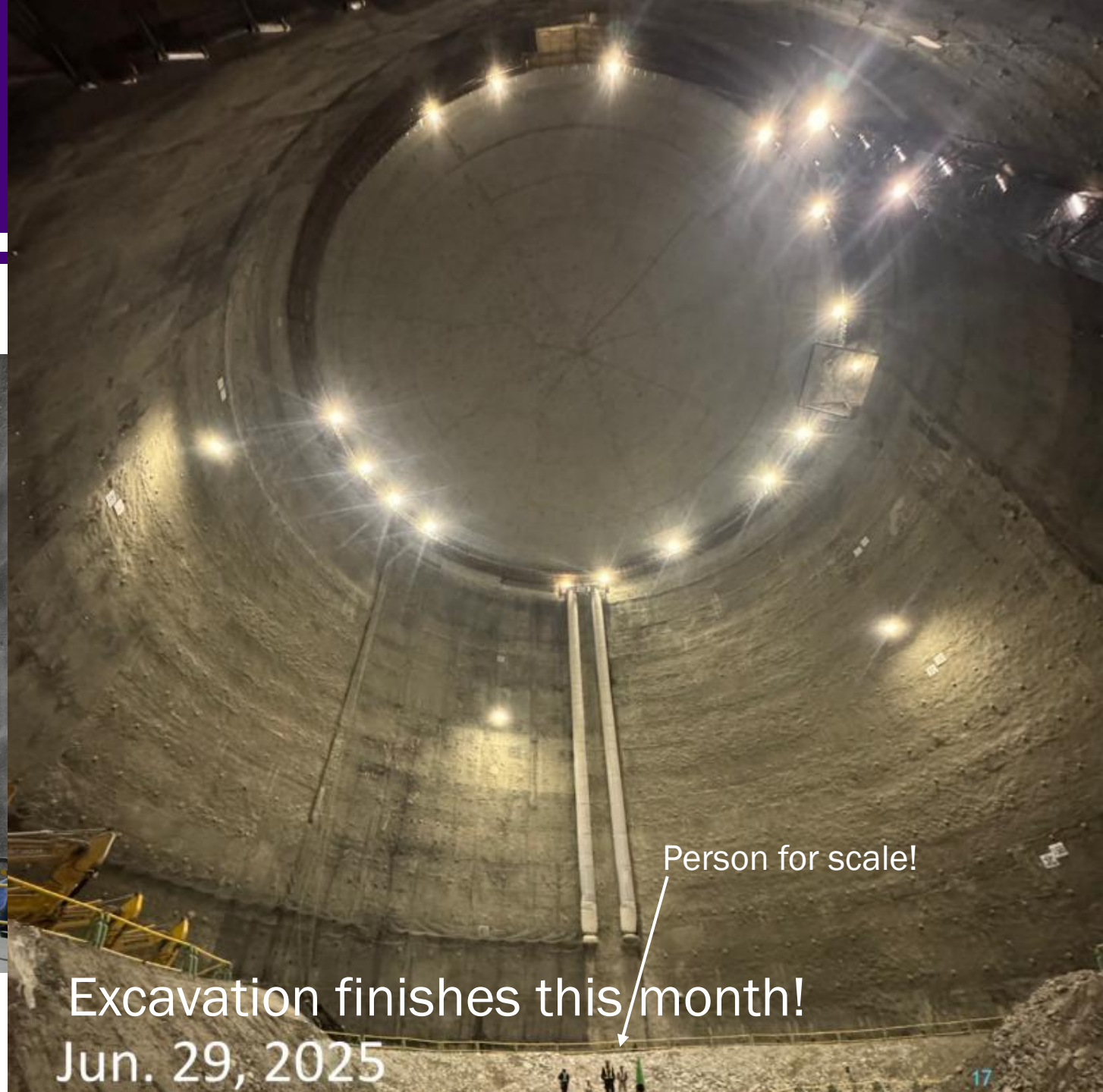


Diffuse Supernova Neutrino Background



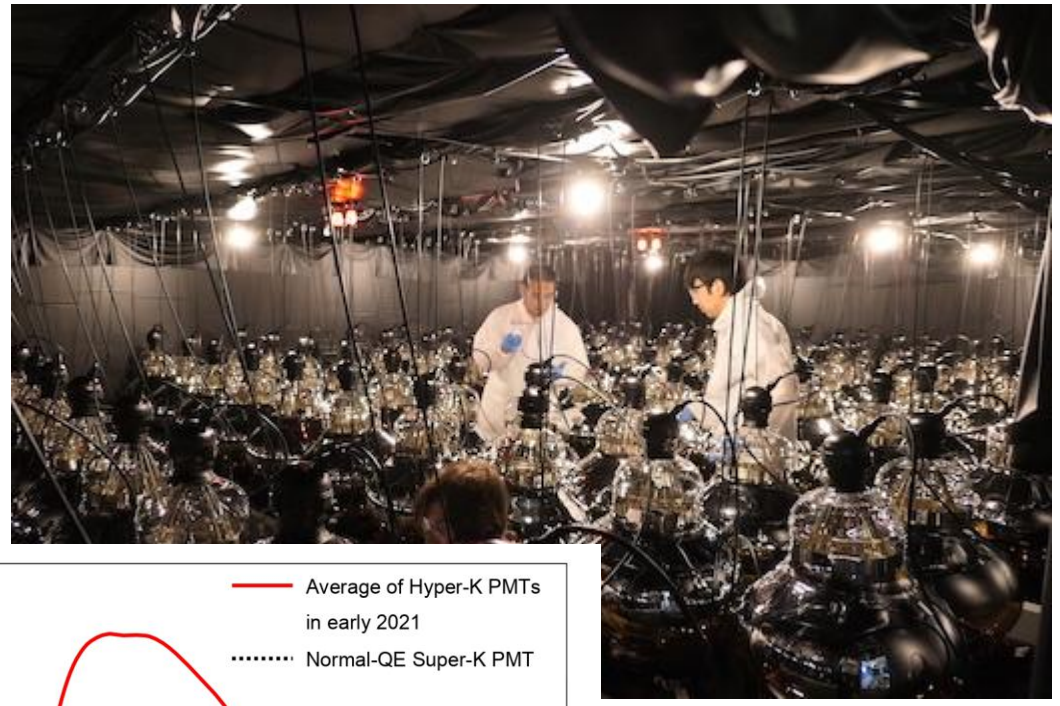
- Neutrinos produced in past core-collapse supernova.
- Measurement of DSBN can inform stellar collapse, star formation rate and heavy element synthesis.
- Expect ~4 events/year with neutron tagging.
- Aim to precisely measure flux and spectrum of these neutrinos.
- Analysis challenge -> atmospheric spallation backgrounds.
- 4.2σ discovery after 10 years.

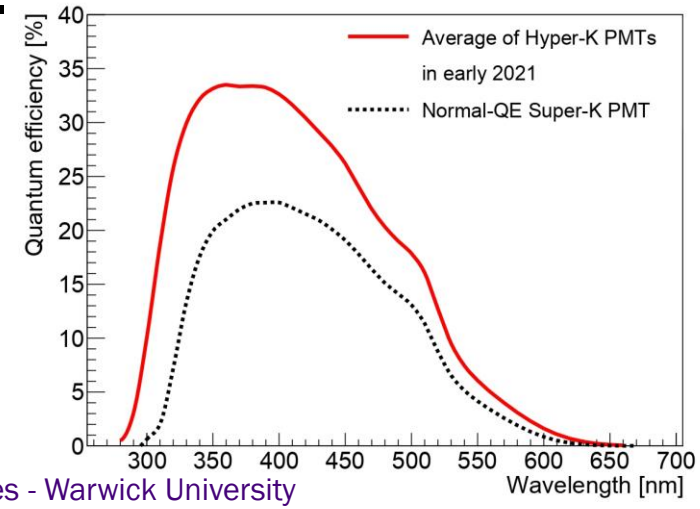
Excavation Status



PMT Status

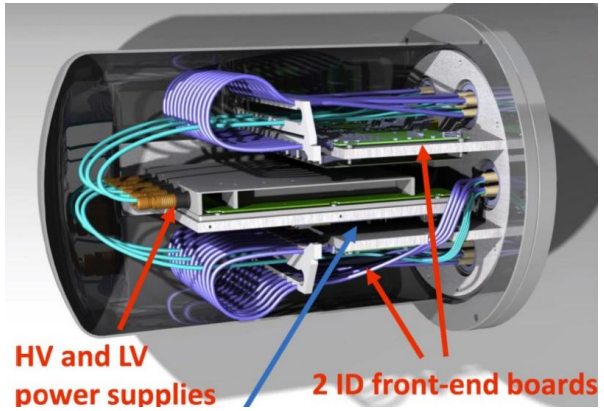
- Improved PMT design (Box and Line dynode) -> higher quantum efficiency (30%), timing resolution (1 ns), pressure tolerance (~10 bar).
- Mass production of 50 cm PMTs ongoing.
- >15,000 PMTs have been delivered. Screen testing signal and visual inspection ongoing in Kamioka and Hamamatsu.
- Dark rate stability measured on smaller batches.





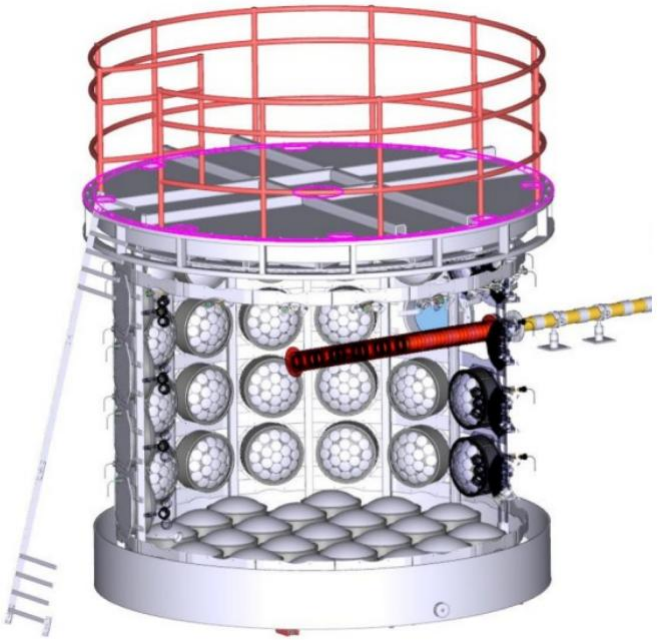
PMT Covers and Electronics Status

- Each 50 cm PMT will be covered by an acrylic dome.
  - Reduce risk of implosion, such as occurred in Super-Kamiokande.
- Tests of covers using mock-up frame in the Mediterranean sea.
- Electronics digitiser will be in the water in pressure vessels.
  - Goal to reduce signal degradation of long cables.
- Two types, one for inner detector PMTs only, and other hybrid inner/outer detector vessel.
- Tests of integrated system both in and out of water are ongoing.



mPMT Status

- Each mPMT unit is comprised of 19 3” PMTs.
- Improves angular acceptance and vertex resolution.
- Different types of mPMT for far detector and IWCD, some include LEDs in design.
- Water Cherenkov Test Experiment (independent collaboration) at CERN measures charge particle scattering.
- WCTE used prototypes for 100 IWCD mPMTs and 5 far detector mPMTs.
- Useful for determining assembly procedure.



Summary

- Physics capabilities of Hyper-Kamiokande are broad and will be world-leading in many sectors.
  - Neutrino oscillation, nucleon decay, astronomical sources and much more.
  - Large detector mass and high-precision are crucial to realise these measurements.
- Upgrades to J-PARC beamline, T2K near detectors and construction of new intermediate water Cherenkov detector ongoing.
- Construction is ongoing with start of operation expected in 2028.
  - Excavation is completing this month, will begin tank construction shortly.