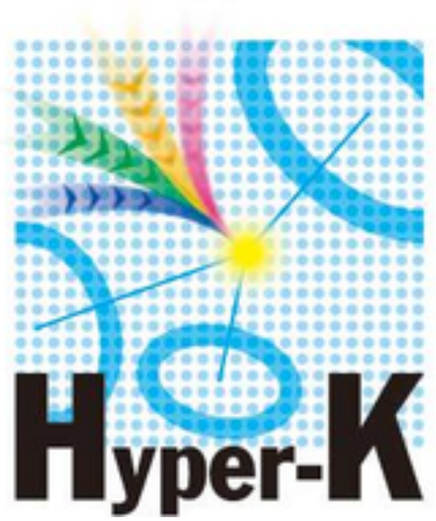
Hyper-Kamiokande Experiment

Detector commissioning and the first neutrino oscillation measurement

RAL PhD Open Day
27 February 2026

Dr Tomislav Vladisavljevic, STFC PPD
Professor Neil McCauley, Liverpool University



Neutrino oscillations

- The discovery of neutrino oscillations has been one of the most concrete evidence of physics beyond the Standard Model
- The Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix tells us how distinct flavour eigenstates (interacting states) and mass eigenstates (propagating states) mix together

Nobel prize for the discovery of neutrino oscillations: Super-Kamiokande and SNO

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

CP Violation

Atmospheric & Accelerator

$\theta_{23} \approx 48^\circ$

$|\Delta m^2_{32}| \approx |\Delta m^2_{31}| \approx 2.5 \times 10^{-3}\ eV^2$

Accelerator & Reactor

$\theta_{13} \approx 8^\circ$

$\delta_{CP} = ?$

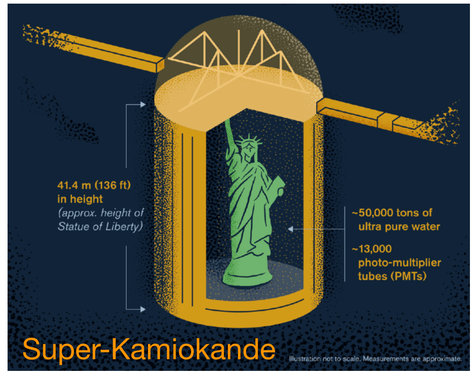
Reactor & Solar

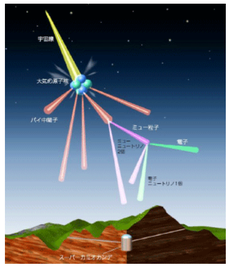
$\theta_{12} \approx 34^\circ$

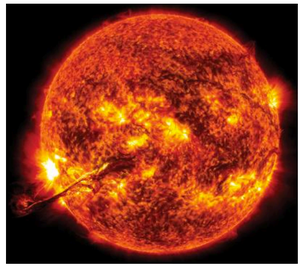
$\Delta m^2_{21} \approx 7.5 \times 10^{-5}\ eV^2$

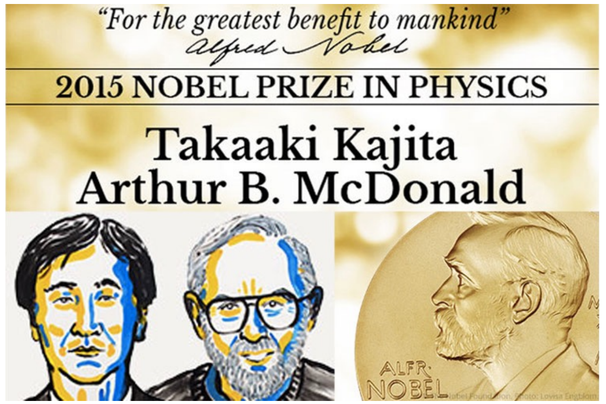
$s_{ij} = sin\ \theta_{ij}$

$c_{ij} = cos\ \theta_{ij}$









Open questions in neutrino oscillation physics

- **Neutrino mass ordering?**
  - Normal $(\Delta m^2_{32} > 0)$ or inverted $(\Delta m^2_{32} < 0)$

- **θ_{23} octant?**
  - Upper $(sin^2\,\theta_{23} > 0.5)$ or lower $(sin^2\,\theta_{23} < 0.5)$
  - $\theta_{23} = 45°$ would indicate an underlying $\mu - \tau$ symmetry of the PMNS matrix

- **CP violation in neutrino sector?**
  - Would like to measure with the same precision as CP violation in hadronic weak interactions
  - $\delta_{CP} \neq 0, \pi$ would indicate $P(\nu_\alpha \rightarrow \nu_\beta) \neq P(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta)$ in vacuum

- Hyper-Kamiokande is well positioned to tackle these questions!

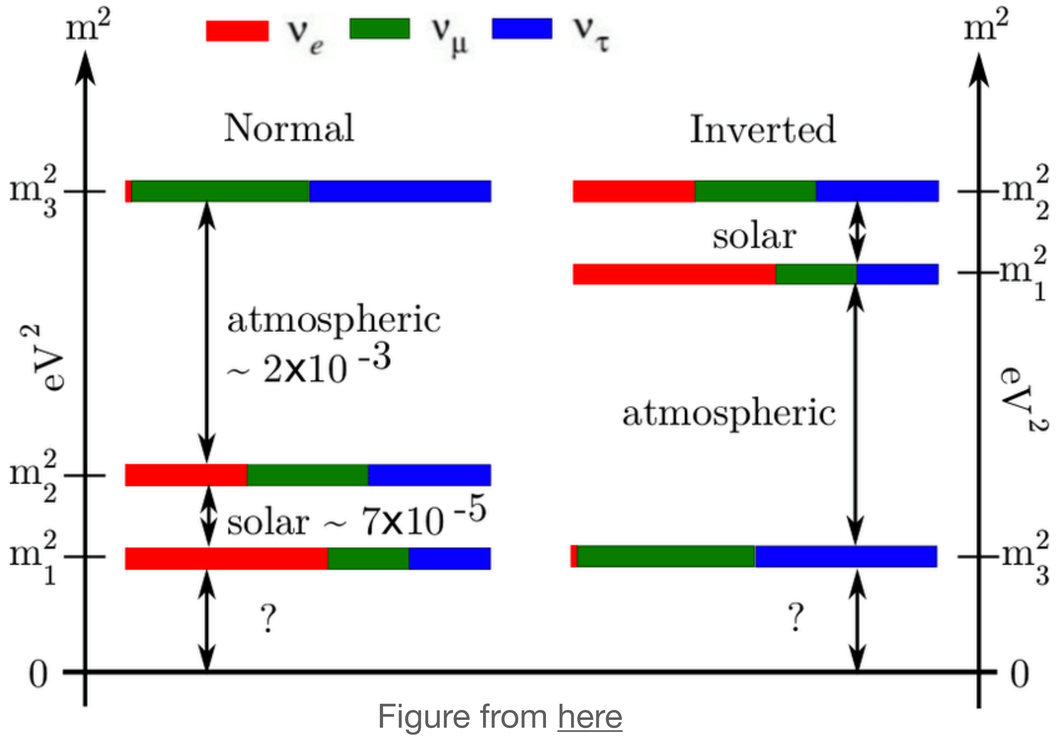
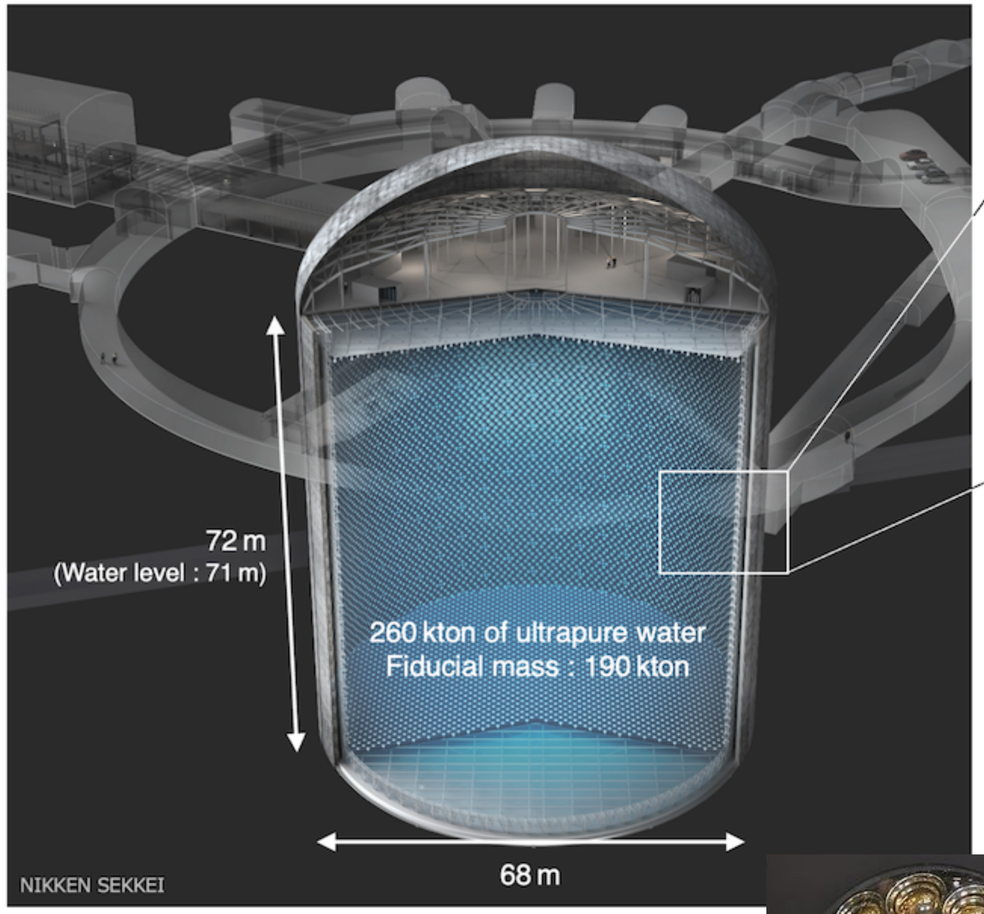


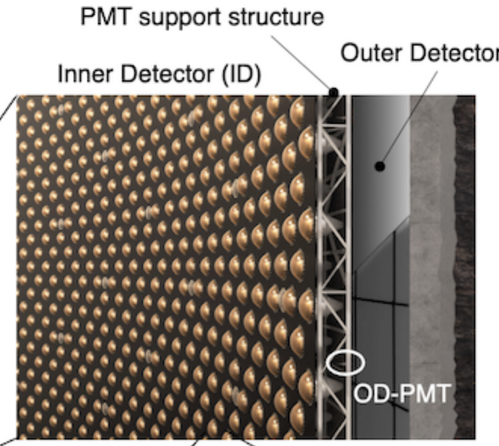
Figure from here

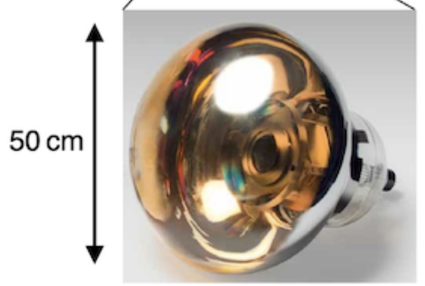
- **PMNS framework validity?**
  - Sterile neutrinos, non standard neutrino interactions, tensions between experiments etc.

Hyper-Kamiokande (Hyper-K) Experiment

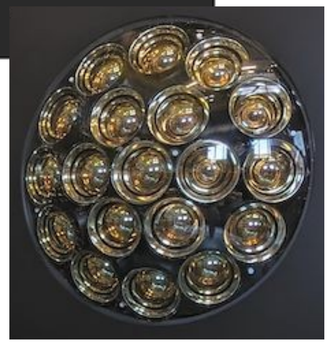
- Next generation water Cherenkov neutrino experiment in Japan
- Building upon the successes of Kamiokande and Super-Kamiokande
- Far detector has ~8 times the fiducial volume of SK
- Instrumented with state-of-the-art photomultiplier tubes (PMTs)
- In the Inner Detector:
  - ~20,000 20” PMTs
  - ~800 mPMTs
- In the Outer Detector:
  - ~3,600 3” PMTs
- Hyper-K has access to a neutrino beam from the J-PARC facility, with multiple near (and intermediate) detectors







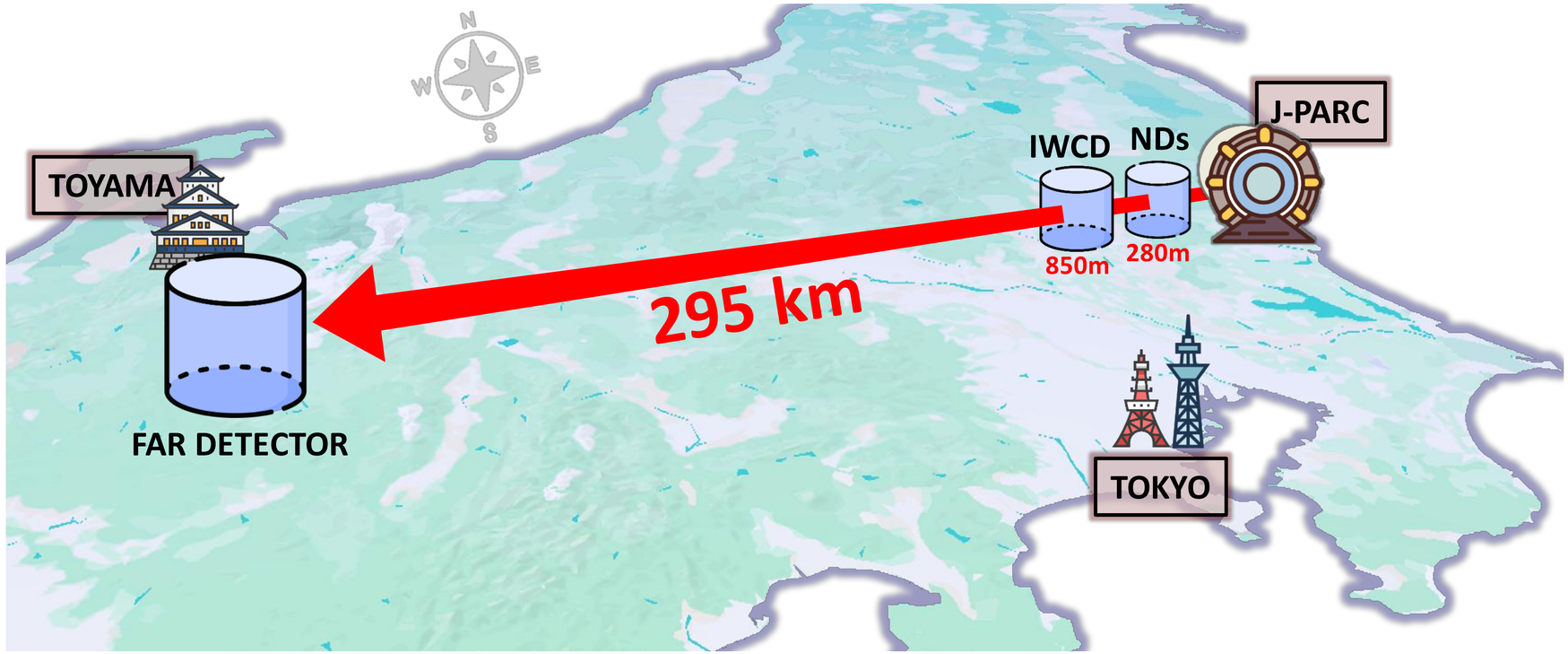
©Hamamatsu Photonics K.K.
New ultrasensitive ID-PMT

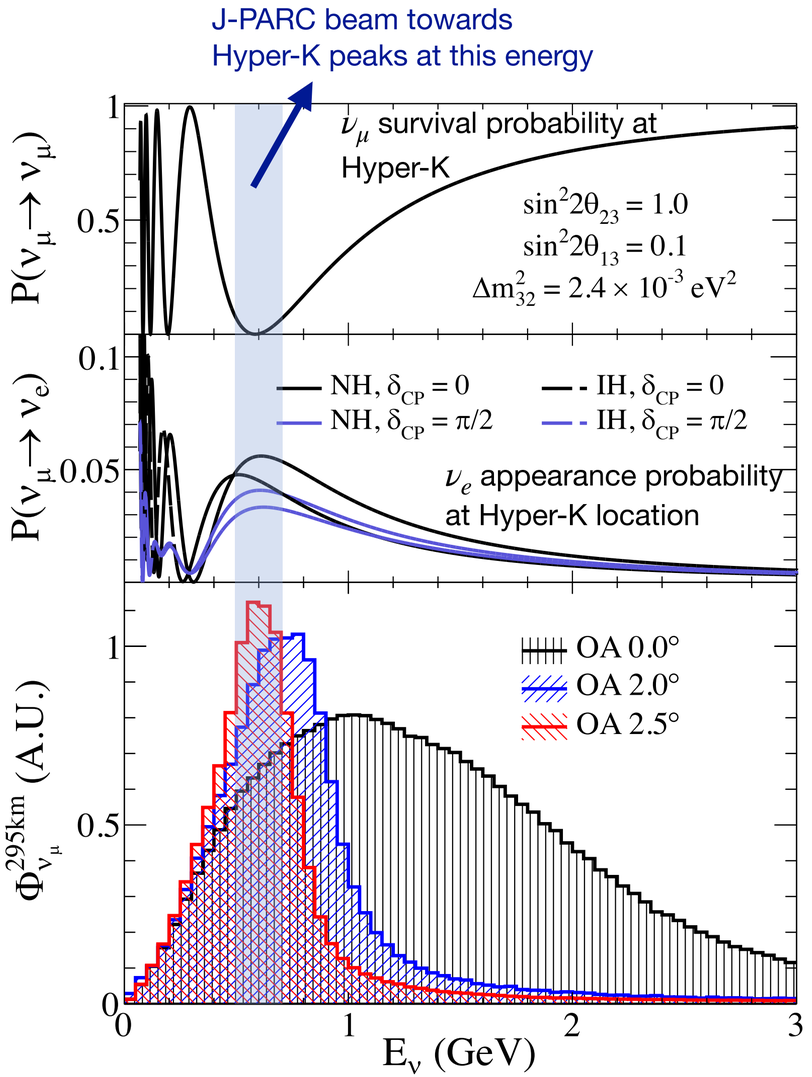


Multi-PMT (mPMT) module

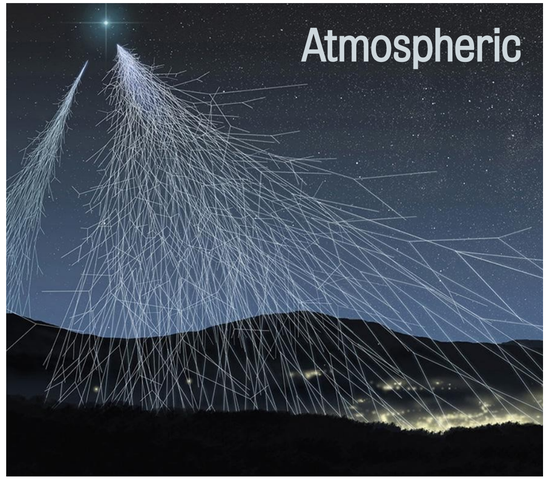
Accelerator-based part of the Hyper-K programme

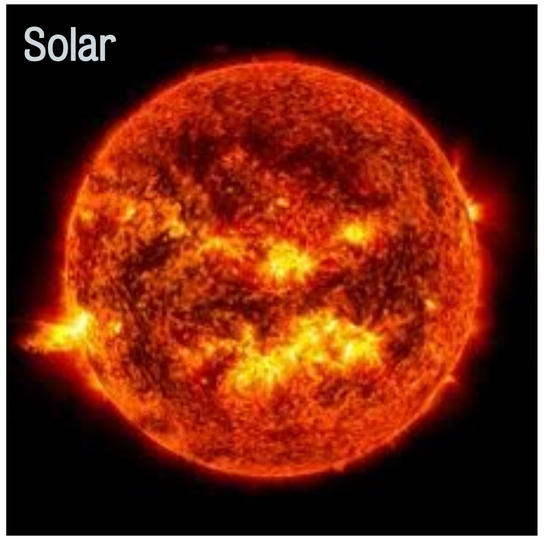
- Japan Proton Accelerator Research Complex (J-PARC) can produce a predominantly muon neutrino (ν_μ) or anti-neutrino ($\bar{\nu}_\mu$) beam
- Near detectors precisely determine the initial beam composition
- Far detector has been positioned at a distance where the oscillation probability for ν_μ (and $\bar{\nu}_\mu$) into other flavours is maximal



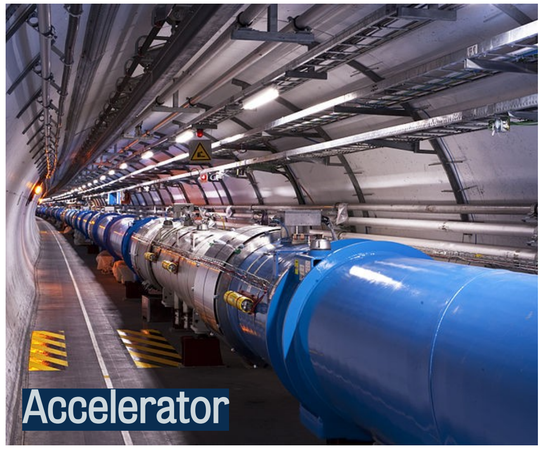


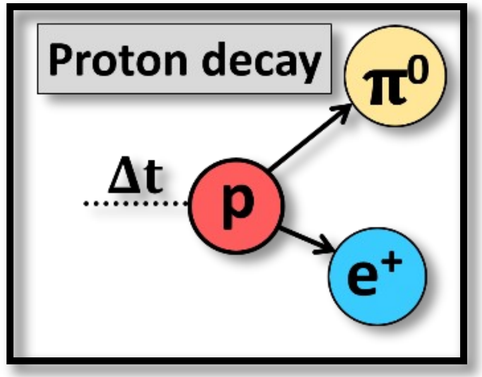
Full Hyper-K Physics Programme

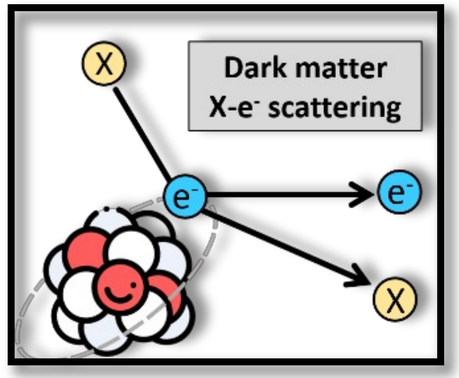




- Hyper-Kamiokande is sensitive to neutrinos from all sources, with unprecedented potential (what if we “see” another Supernova, first since SN1987?)
- Also Grand Unified Theories beyond the Standard Model (expect world’s best constraint on proton decay)



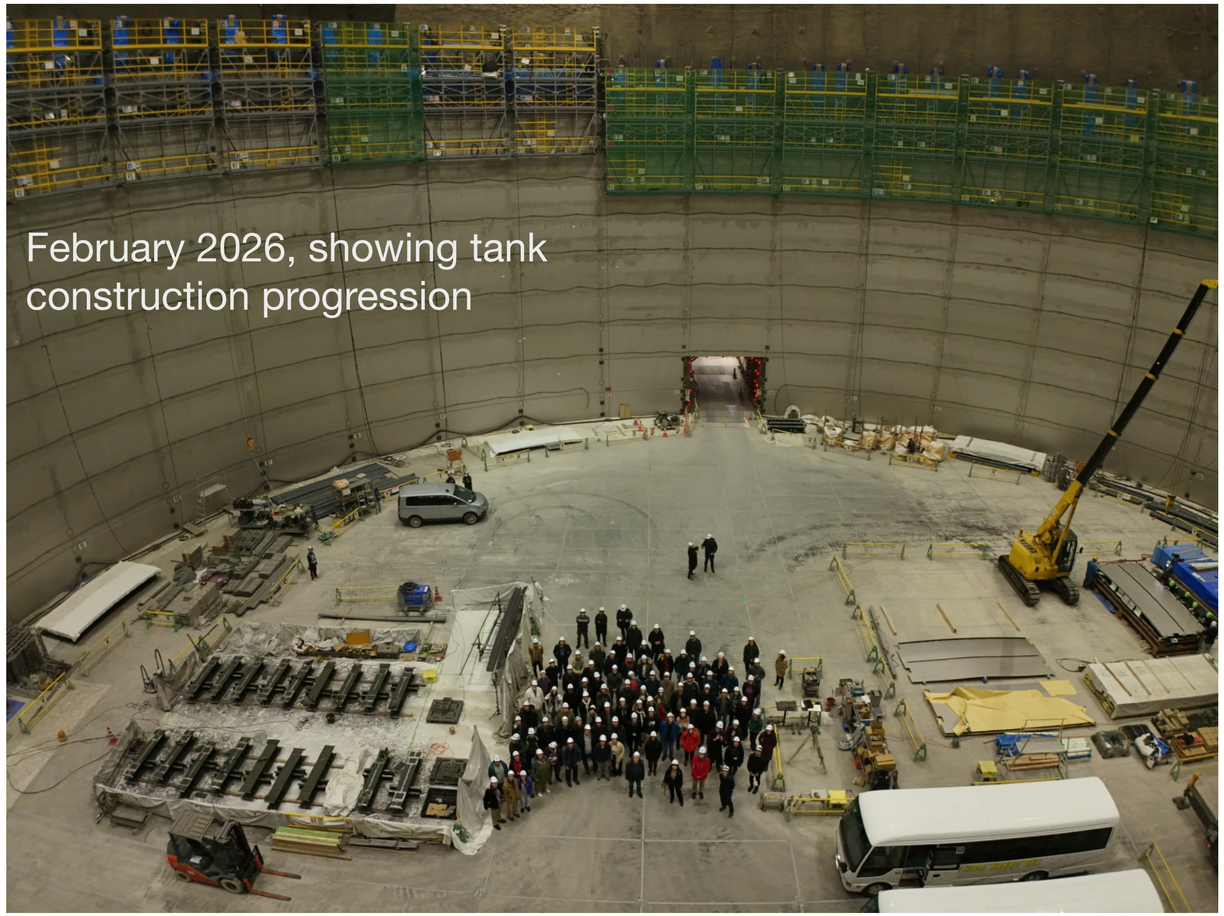




Cavern Excavation Status

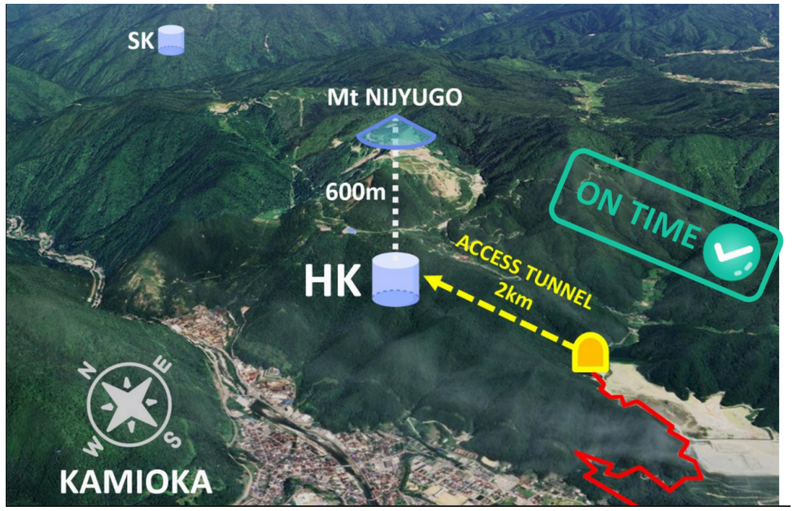
- The cavern excavation has been completed in July 2025 (see video here on the process)
- Tank construction is currently ongoing, with PMT installation scheduled for 2027

The Royal Albert Hall could just about fit twice inside the Hyper-K cavern…



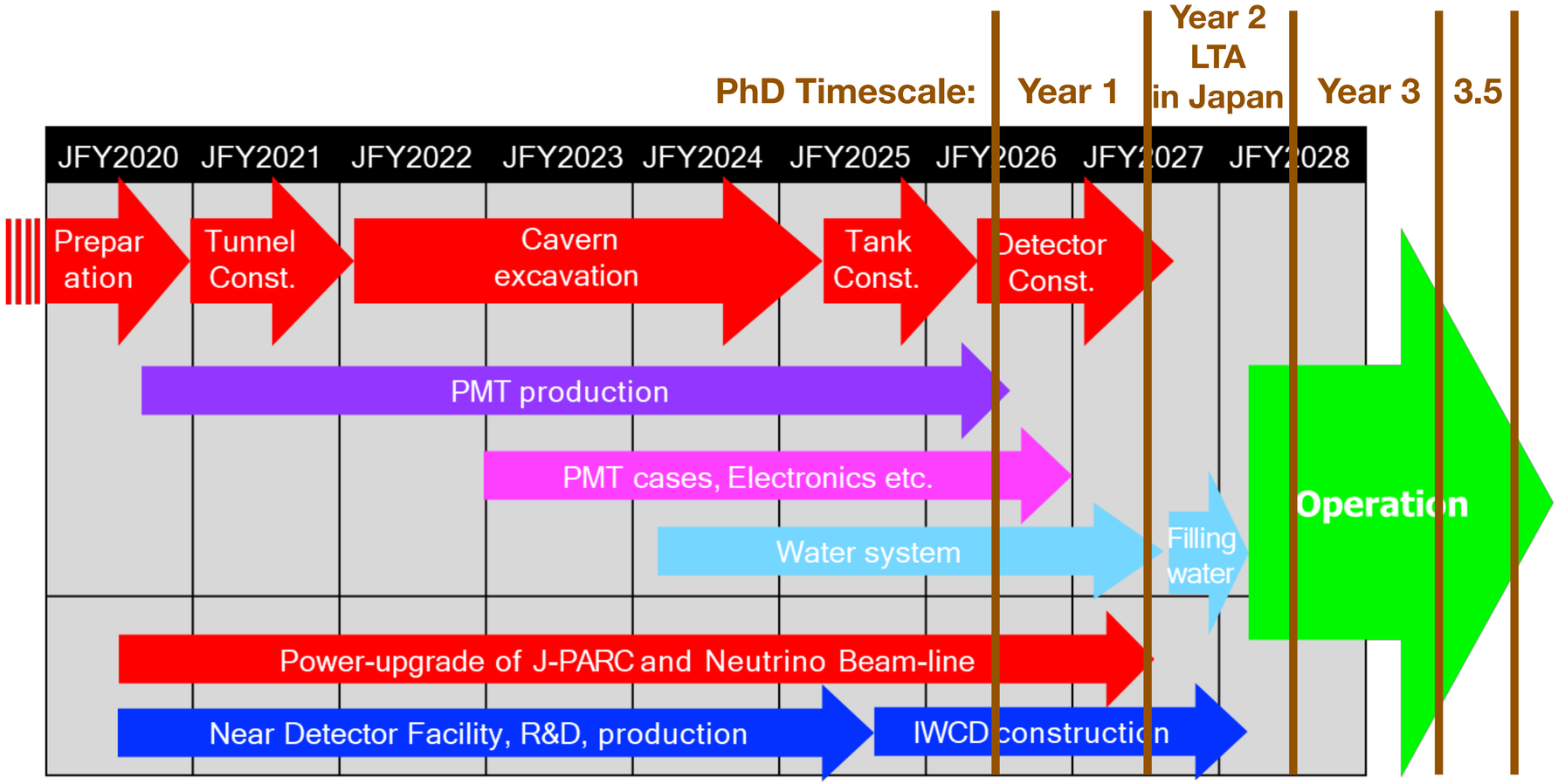
Hyper-Kamiokande Collaboration

- International scientific collaboration, with a strong UK involvement (2nd only to Japan) and UK expertise across all areas
- 24 countries, ~106 institutes, ~650 members (2025)
- Meets 3 times per year in Japan for collaboration meetings
- Annual Hyper-K UK meetings to consolidate UK efforts



Hyper-K Summer Collaboration Meeting in Toyama, Japan, June 2025

Hyper-K Timeline: Experiment & PhD Project



- **Highly timely project**, with a unique opportunity to contribute to 3 major stages of the experiment:
  - commissioning
  - data collection
  - first physics exploitation
- Hyper-K prepares for the prompt analysis of the 1st year of data, with measurements in individual analysis strands (long-baseline, atmospheric, solar, proton decay etc)
- Opportunities in this PhD project for high impact contributions to the physics of Hyper-K

1983 Kamiokande 1996

Detection of cosmic ν (SN1987A, solar)

1996 Super - Kamiokande …

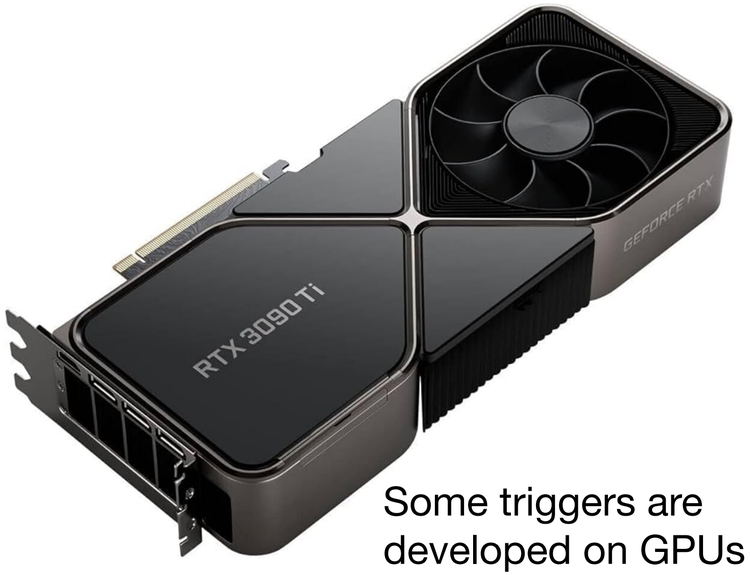
Discovery of atmospheric ν oscillation

2028 Hyper – Kamiokande …

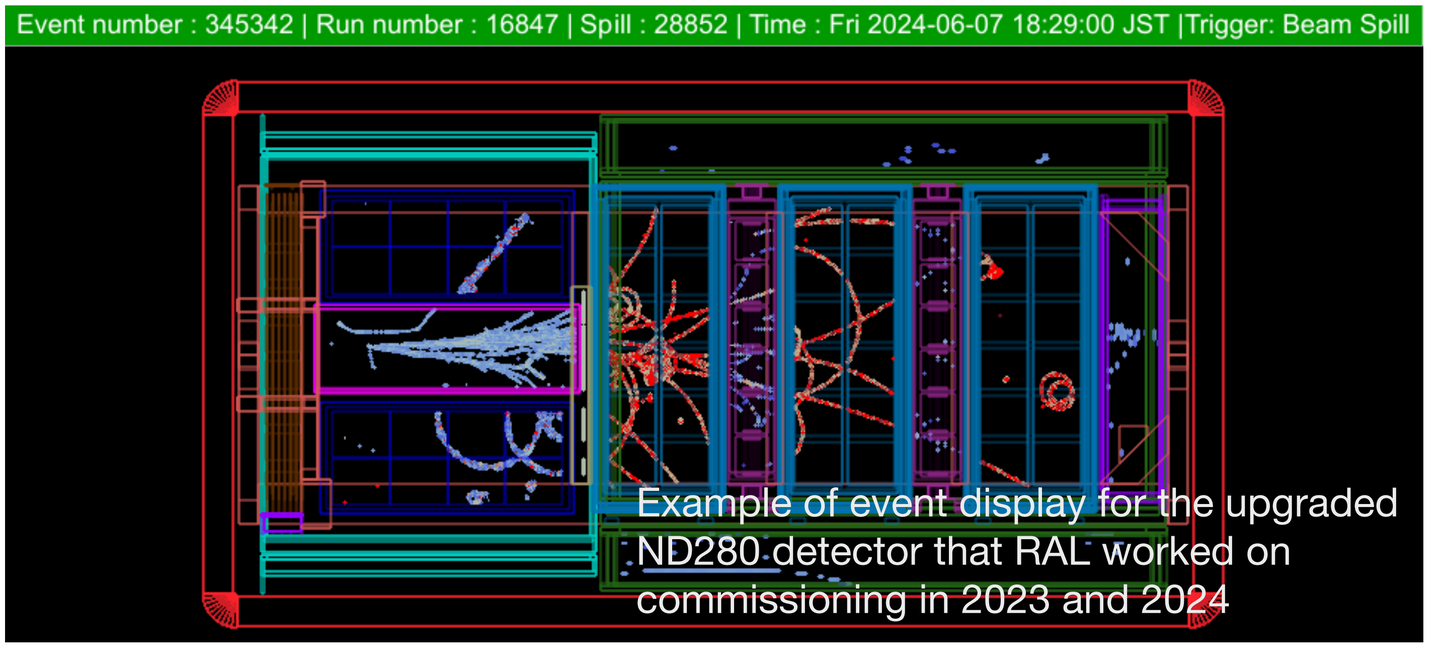
Broad program for future discoveries

Data Acquisition System for Hyper-K

- Hyper-K will be continuously running once it goes live
- The Data Acquisition (DAQ) system will be the “brain” of our detector, which will decide which data is interesting to save to disk
- RAL has already built the DAQ system for Hyper-K’s near detector (ND280), and is leading the development of triggers for the Hyper-K far detector
- Trigger development, commissioning, and optimisation for physics data forms part of the project



Some triggers are developed on GPUs

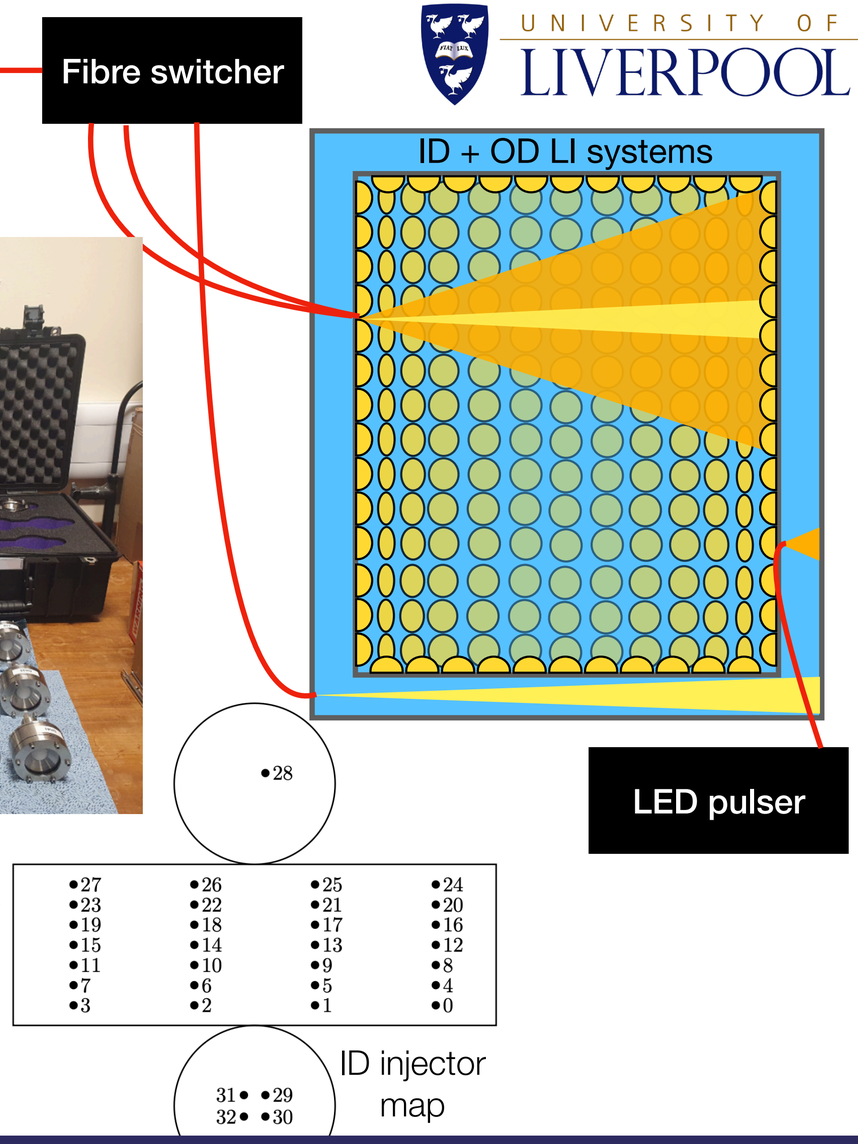


Example of event display for the upgraded ND280 detector that RAL worked on commissioning in 2023 and 2024

Light Injection (LI) System for Hyper-K

- Aim of the LI system is to inject known pulses of light to characterise the response of PMTs and water parameters, as well as to monitor water quality
- 33 ID injector positions featuring the collimator and diffuser, plus 12 OD collimators
  - Illuminated by 6 pulsed laser sources
  - Fibre switching device to move between injectors
- 122 OD diffuser positions
  - Illuminated by pulsed laser sources
- Liverpool is leading these efforts (Neil is Convenor of the Hyper-K Calibration Group), and development and deployment of the light injection system, and the subsequent PMT and water response characterisation is part of this project

Light injection system developed at Liverpool, ready to be shipped to Japan

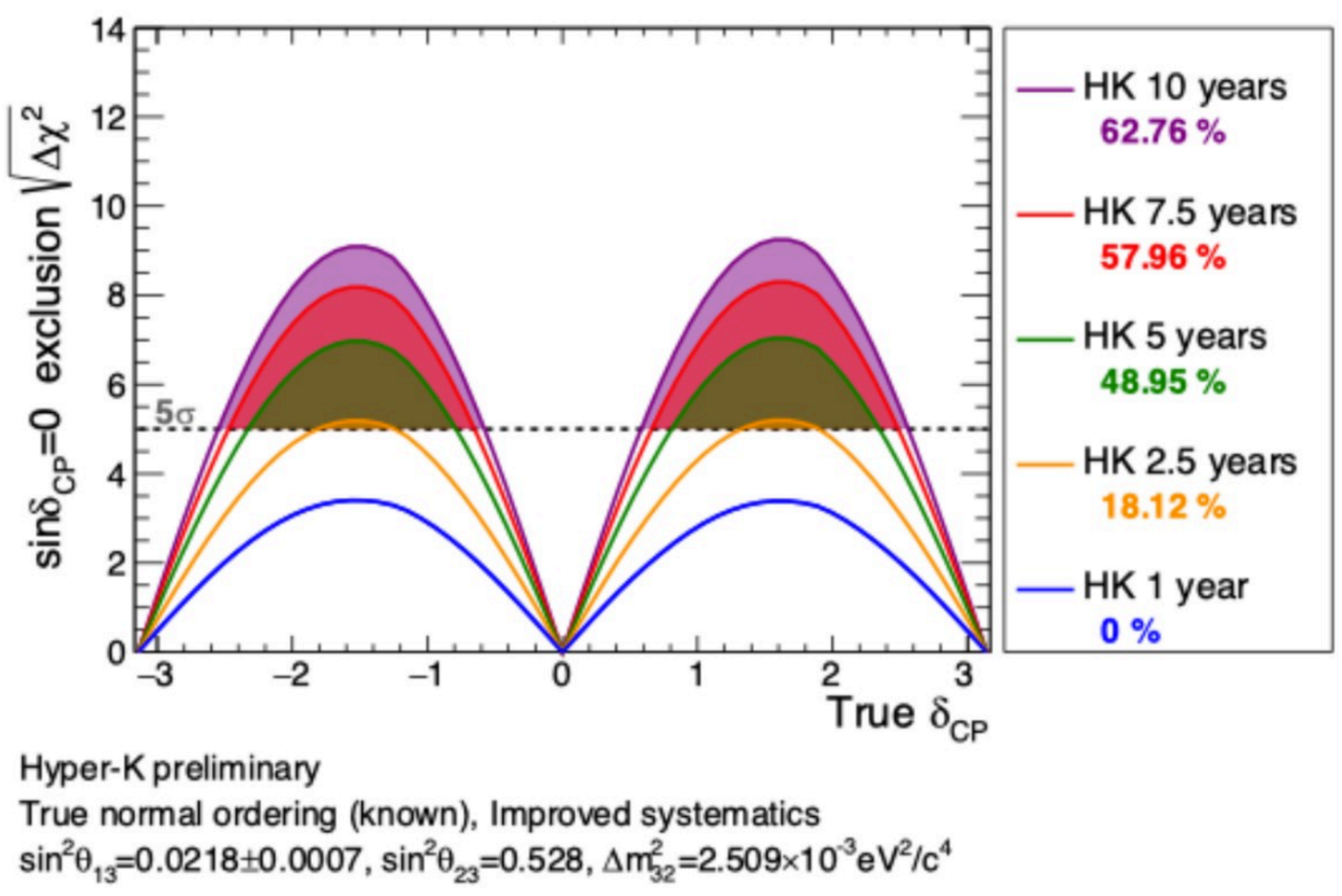


PhD Project Plan

- Interface between DAQ and Light Injection system (1st year mini project): *crucial in early stages of commissioning for the development of the LI trigger and LI slow control*
- Commissioning of the DAQ and LI systems for the Hyper-K far detector (2nd year)
- Long Term Attachment (LTA) in Japan in 2nd year, for the end of the detector construction stage, the water-filling stage, and the beginning of data collection
  - Mostly overlapping while on LTA with Neil and myself (Neil will be on sabbatical in Japan leading calibration efforts, and I will be there for DAQ commissioning) for full support
- Systematics development, *focusing on a bottom-up approach to understand how the detector response varies as underlying parameters change* (2nd year); Examples of parameters to consider:
  - Water Absorption, scattering (Rayleigh, Mie, Raman)
  - PMT gain, efficiency, angular response, reflections
- Further analysis opportunities (3rd year): *implementation of systematics as inputs for oscillation analyses, selection development for far detector samples etc. (flexible depending on student's interests)*
- To sum up: 1st year in Liverpool, 2nd year on LTA in Japan, 3rd year in RAL + 0.5 year writing up

Discovery Potential of Hyper-K: CP Violation

- Sensitivity of Hyper-K to new physics is world leading in many areas
- Less than 3 years to discovery of CP violation if mass ordering is normal and $\delta_{CP} = -\pi/2$ (currently preferred by data)
- 5σ discovery of CP violation in 10 years for ~60% of true δ_{CP} values (assuming known mass ordering, which including atmospherics data can address)



Spanning both detector commissioning and high-impact first analysis opportunities, this PhD project is uniquely timed to allow a high impact contribution to one of the leading HEP experiments!

We are looking for a motivated candidate to join us!

*Shown is the water surface cleaning during the 2018/19 Super-Kamiokande refurbishment work