2022 PPAP Community Meeting

Neutrinos: Japan

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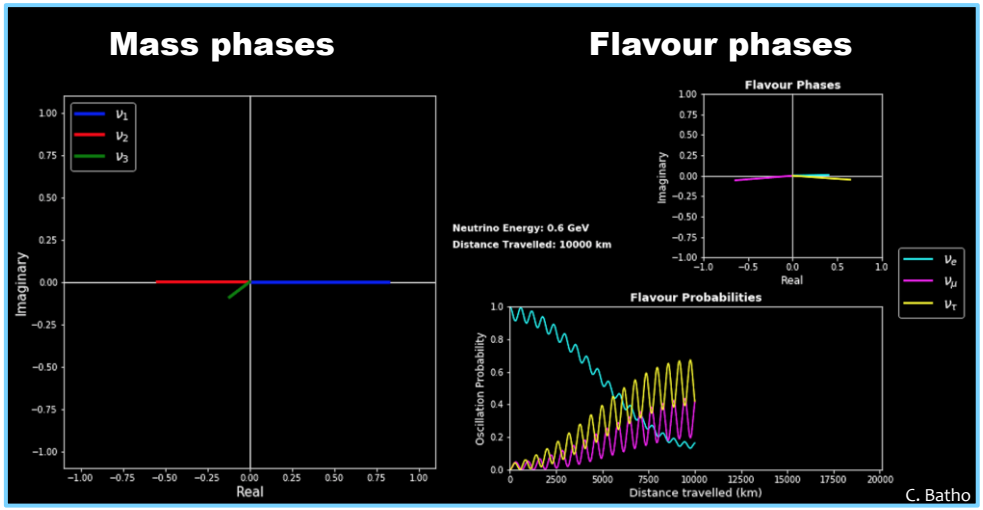
University of Glasgow

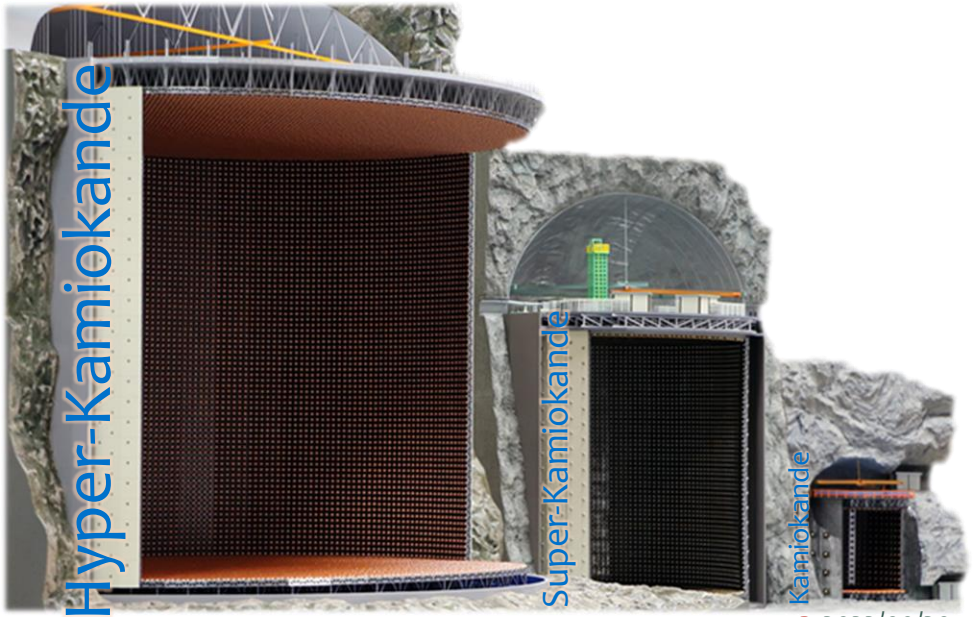
T2K Hyper-Kamiokande

Outline

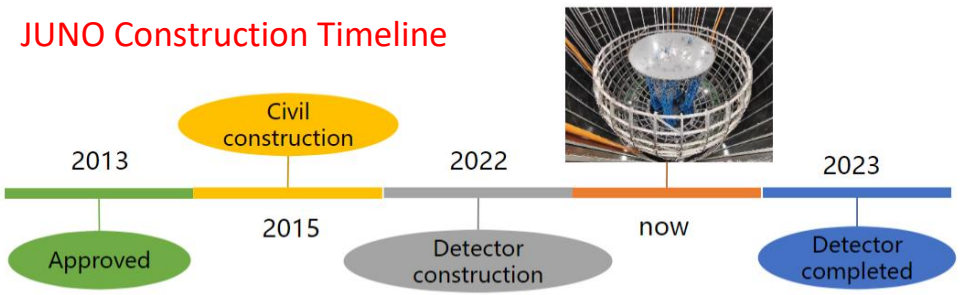
- Brief recapitulation of neutrino physics
- JSNS
- The present: T2K & Super-K
- The future: Hyper-K
- UK involvement

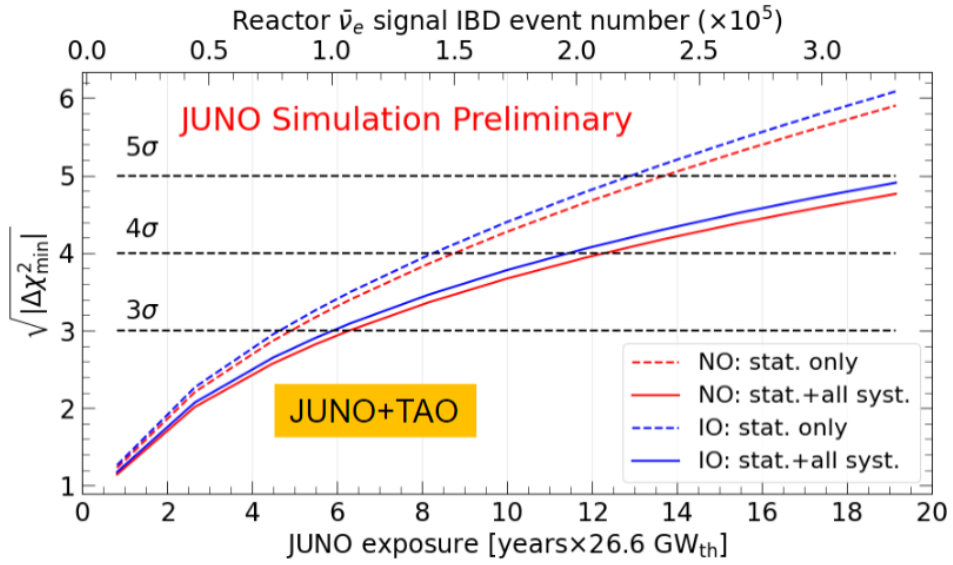
From Neutrino '22





¬Outline





Not covered:

Non-oscillation (neutrino) physics

Other neutrino projects in Asia:

- Reactor SBL
- Daya Bay & RENO
- JUNO

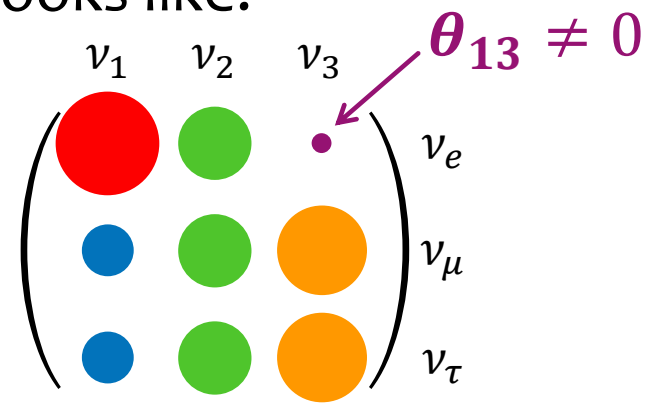
JUNO in particular can determine MO (~2030), and improve knowledge of Δm^2 & θ_{12}.

@ U. Warwick

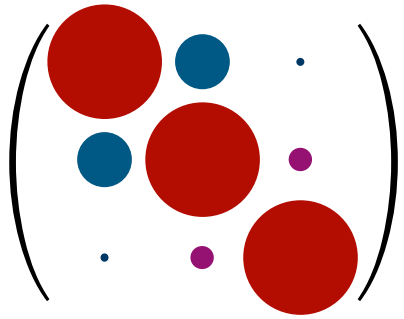
Open questions in neutrino oscillation

2020~ : precision measurement — focus on 3-neutrino effects.

- We know fairly well what the mixing matrix looks like:

$|U_{\mathrm{PMNS}}|^2 \simeq$ 

and it's nothing like the CKM matrix

$|V_{\mathrm{CKM}}|^2 \simeq$ 

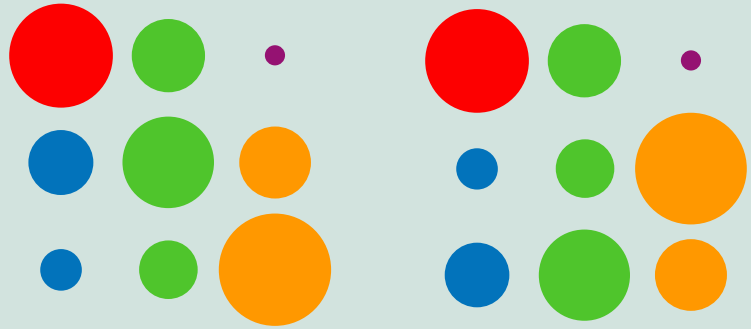
Open questions in neutrino oscillation

2020~ : precision measurement — focus on 3-neutrino effects.

- We know *fairly* well what the mixing matrix looks like:

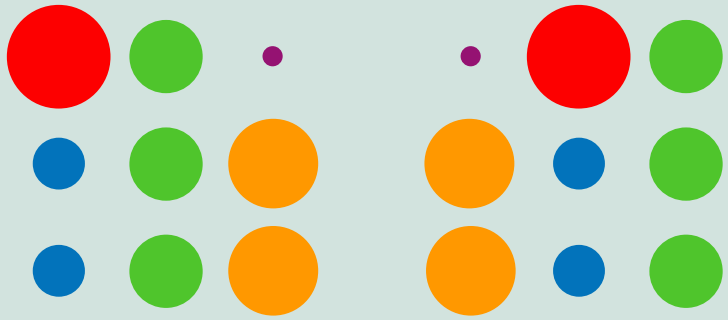
$$|U_{\mathrm{PMNS}}|^2 \simeq \begin{pmatrix} \nu_1 & \nu_2 & \nu_3 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{pmatrix} \begin{matrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{matrix}$$

Octant degeneracy



Lower ($\theta_{23} < 45°$) Upper ($\theta_{23} > 45°$)

Mass Ordering [Hierarchy]



Normal (NO) Inverted (IO)

CP Violation

Complex mixing of these 4 elements causes

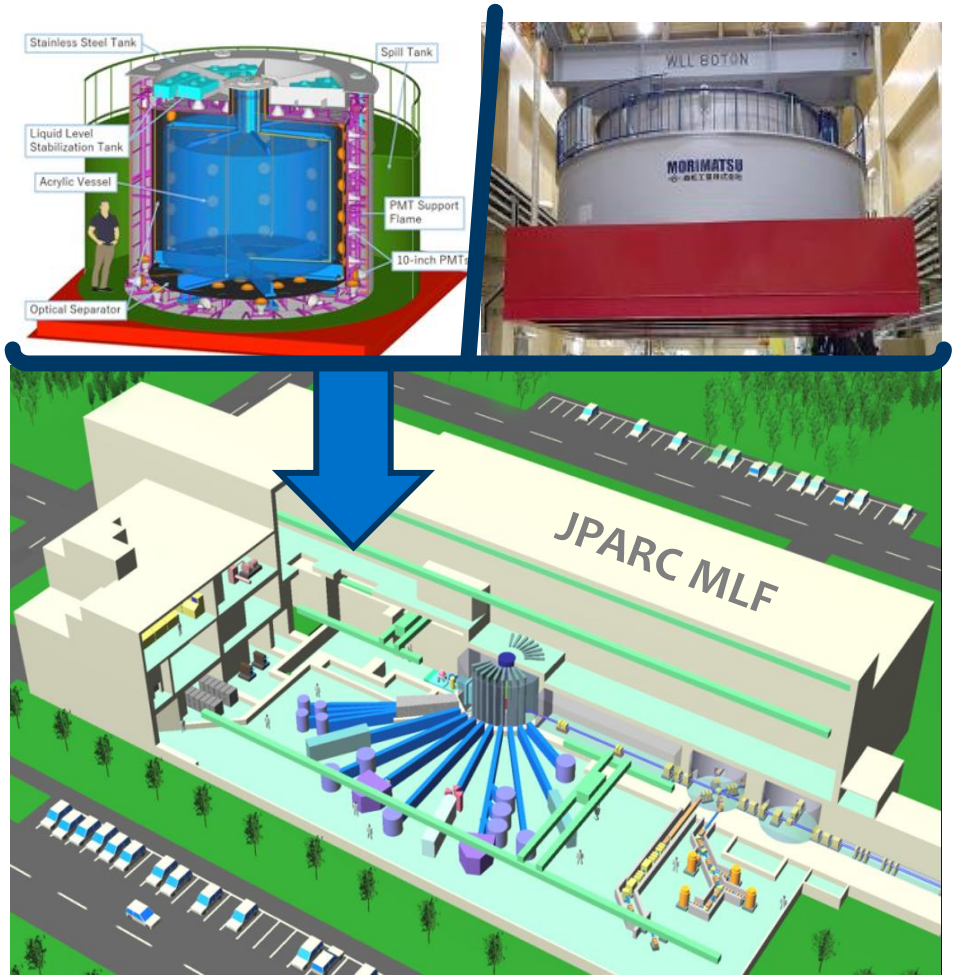
$$P(\nu_\alpha \to \nu_\beta) \neq P(\bar{\nu}_\alpha \to \bar{\nu}_\beta)$$

Key parameter: $\boldsymbol{\delta_{CP}}$

Short baseline physics: JSNS²

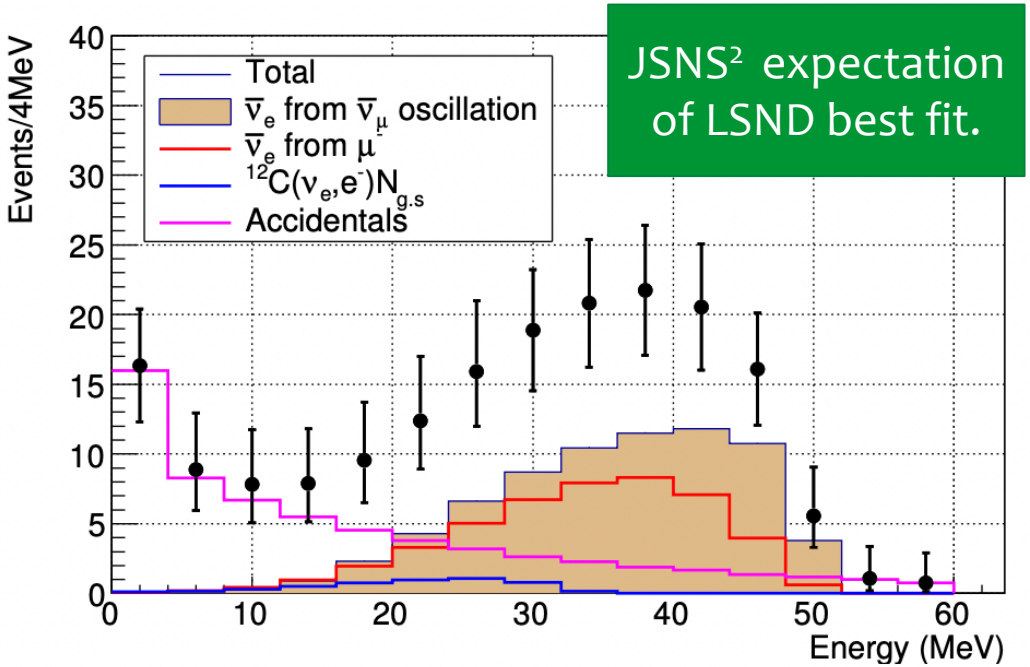
J. Park, https://zenodo.org/record/6681910

@ U. Sussex

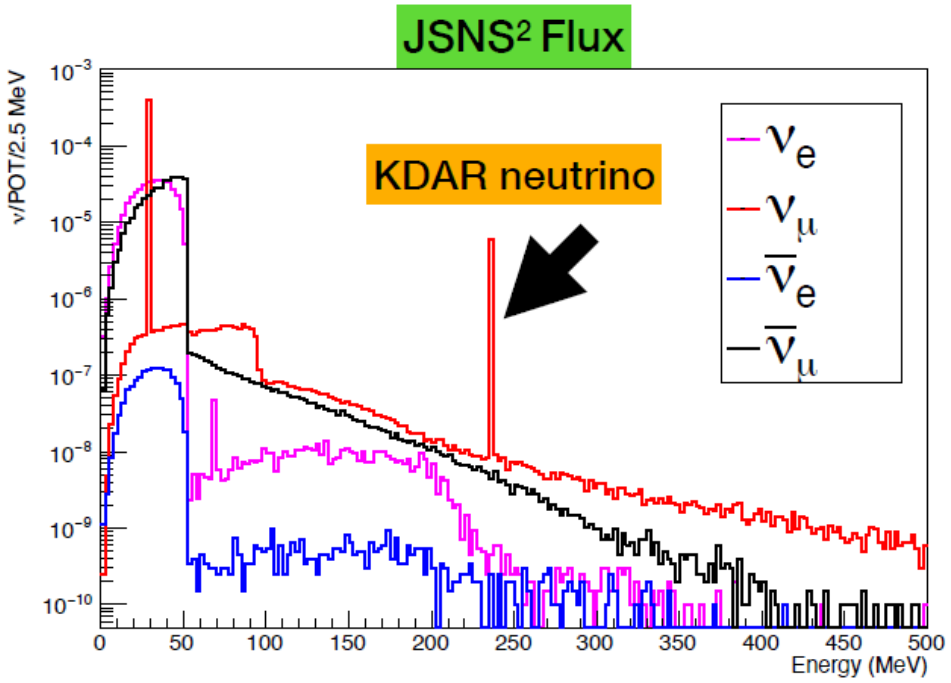


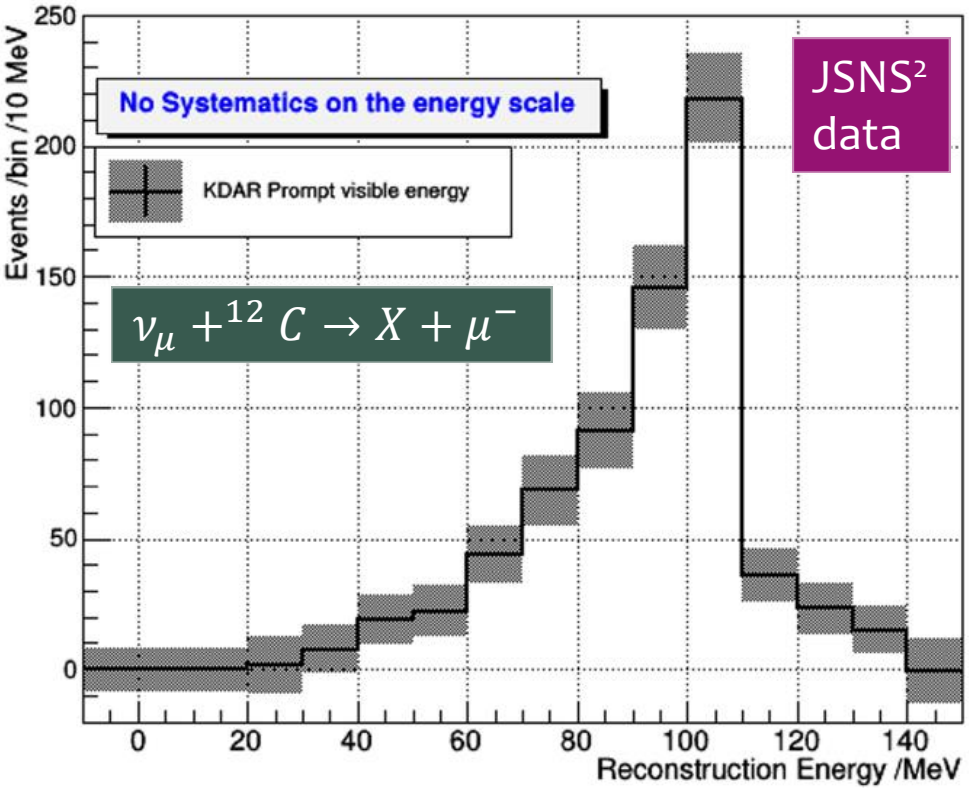
- DIN-based LS with Gd
- Taking physics data since 2021

Investigate LSND signal with modern detector technologies & neutrino interaction models



Kaon decay at rest





Beam dump source of **monoenergetic** 236 MeV neutrinos

- **Unique** source for ν_μ interactions; no integral over flux
- Fiducial test for neutrino generators in the 100-MeV regime

Present: T2K & Super-K

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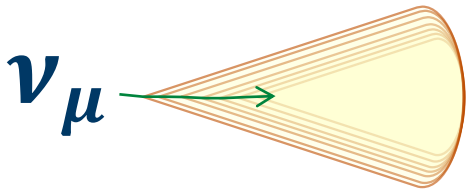
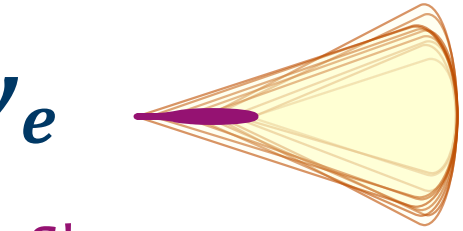
Super-Kamiokande events



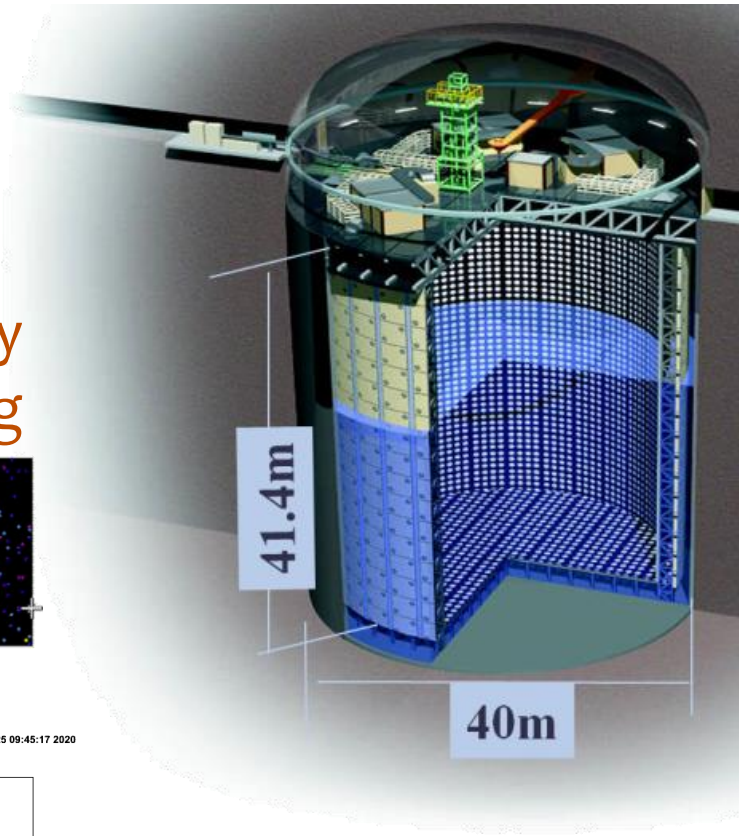
Track

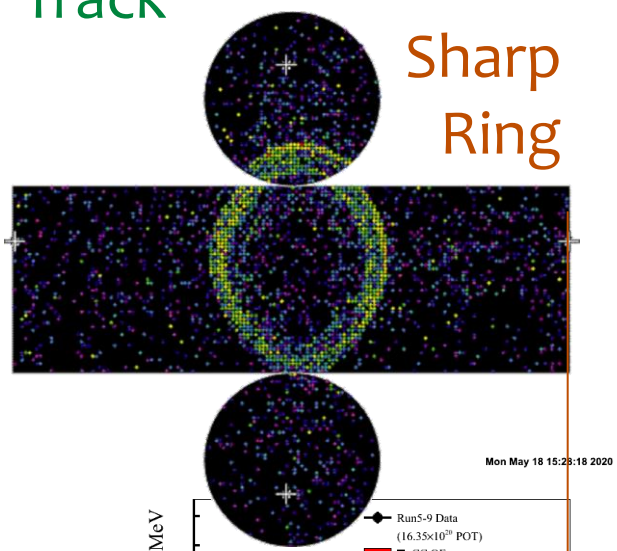
Sharp Ring

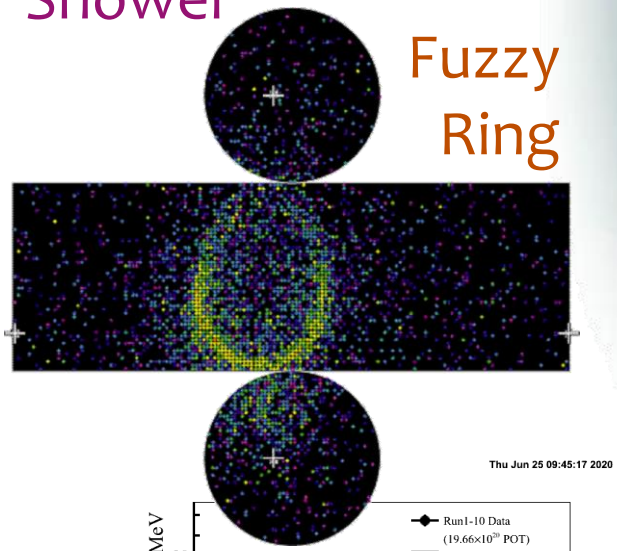


Shower

Fuzzy Ring





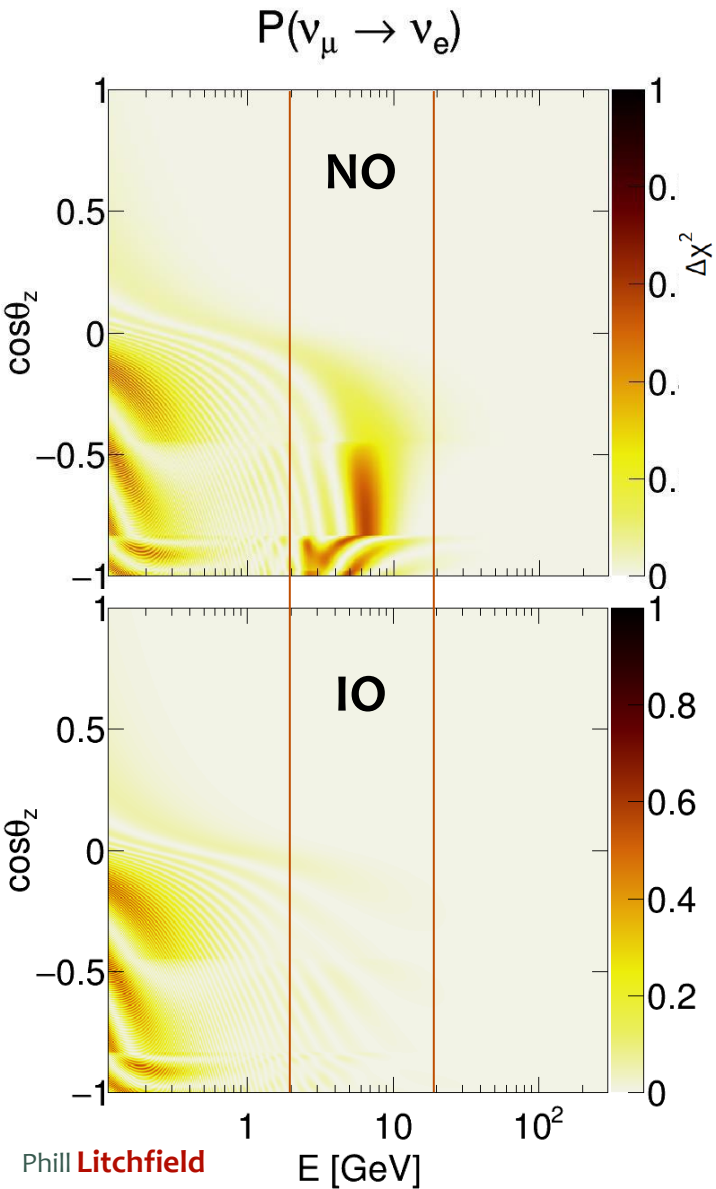


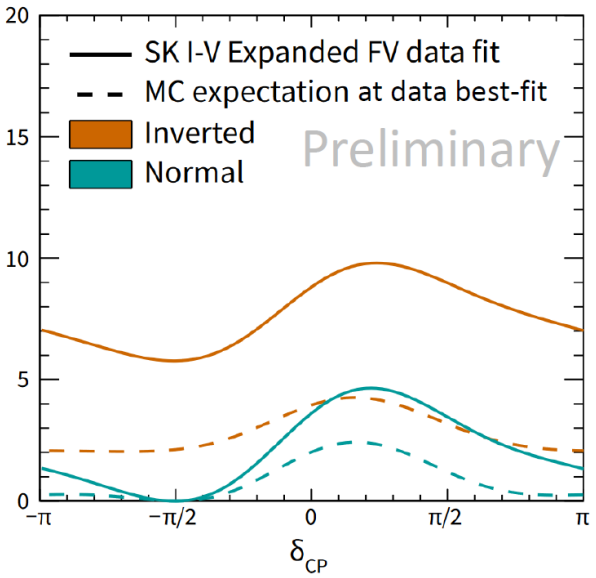
ν_μ inform $\theta_{23}, \Delta m^2_{3i}$

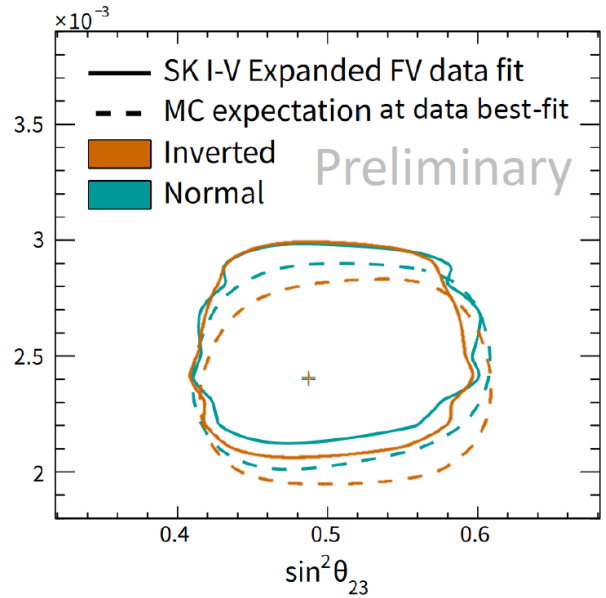
ν_e inform δ_{CP}, MO

SK I~V atmospheric analysis

L. Wan, https://zenodo.org/record/6694761



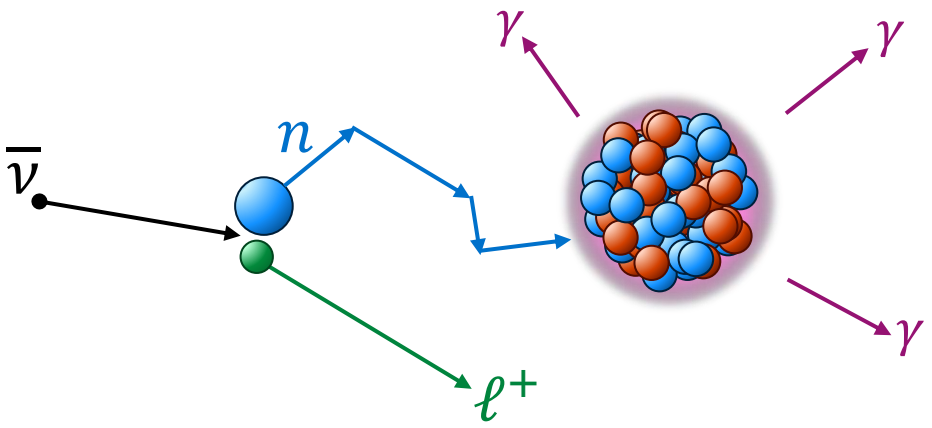




- All pure-water data now included!
- Measurement of Δm^2_{32}, θ_{23} and δ_{CP} are consistent with accelerator experiments
- Mass ordering discernible due to MSW resonance between 2~ 20GeV

$$\chi^2_{\mathrm{IO,bf}} - \chi^2_{\mathrm{NO,bf}} = 5.8\ (\sim 2.4\sigma)$$

Gadolinium loading



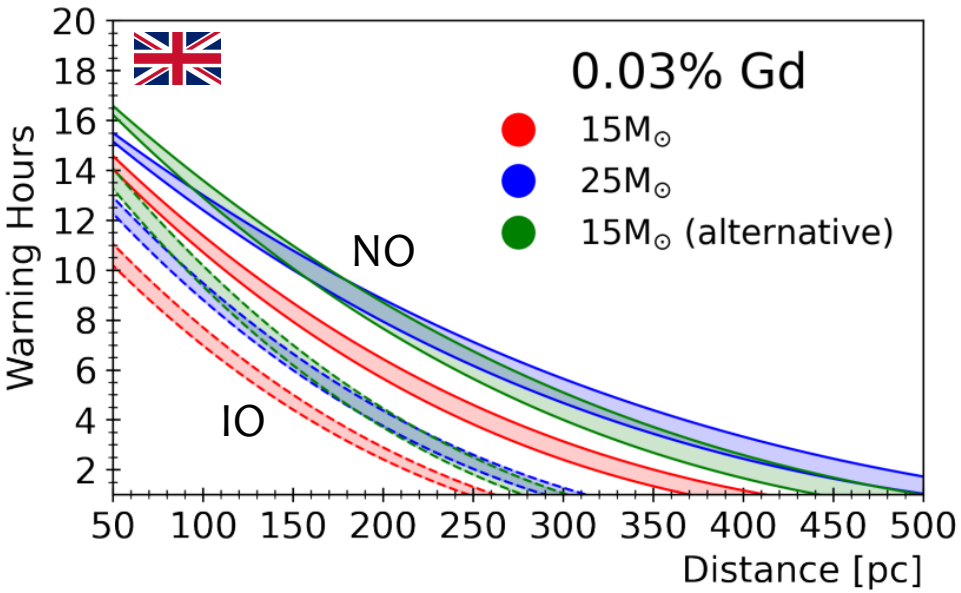
Gadolinium is used to capture neutrons ejected by antineutrino interactions

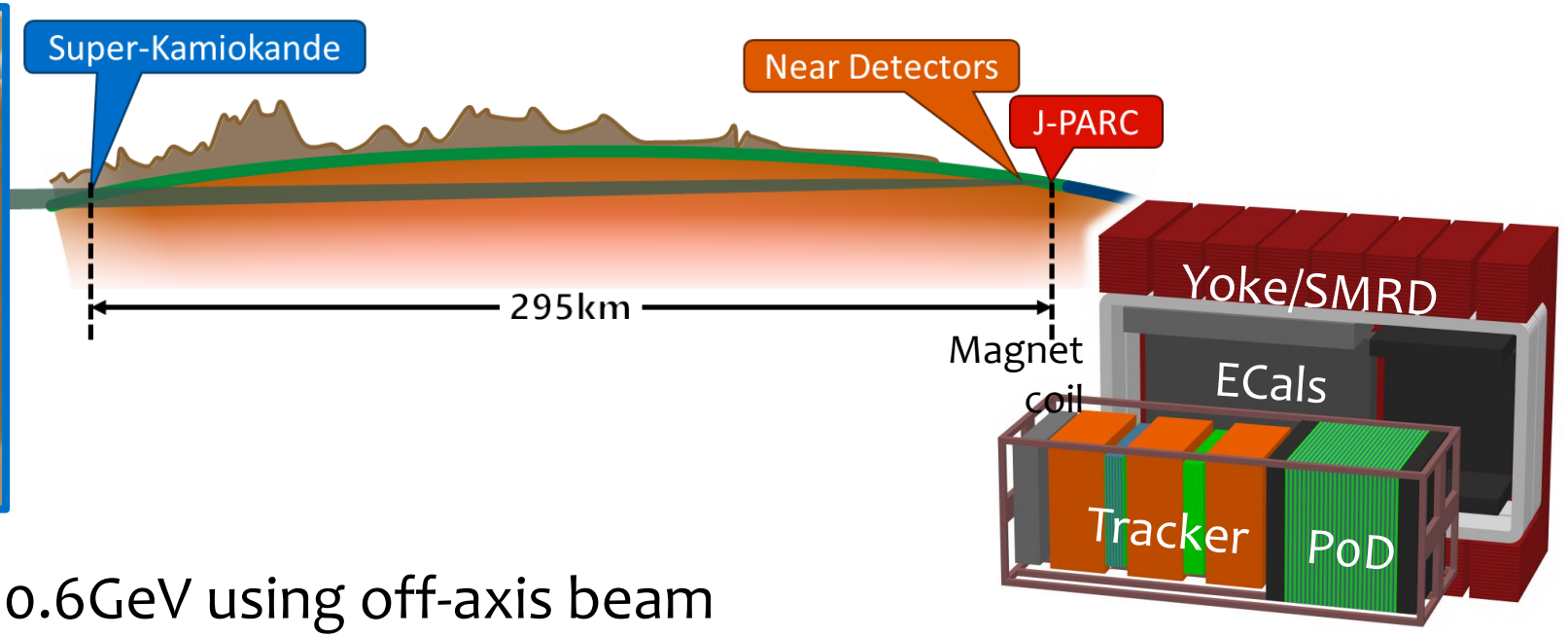
- Tag antineutrino events CP
- Hadronic energy estimate by neutron travel distance

Improve T2K & SK atmospheric…

…but primary reason is to enhance sensitivity to SN $\bar{\nu}$.

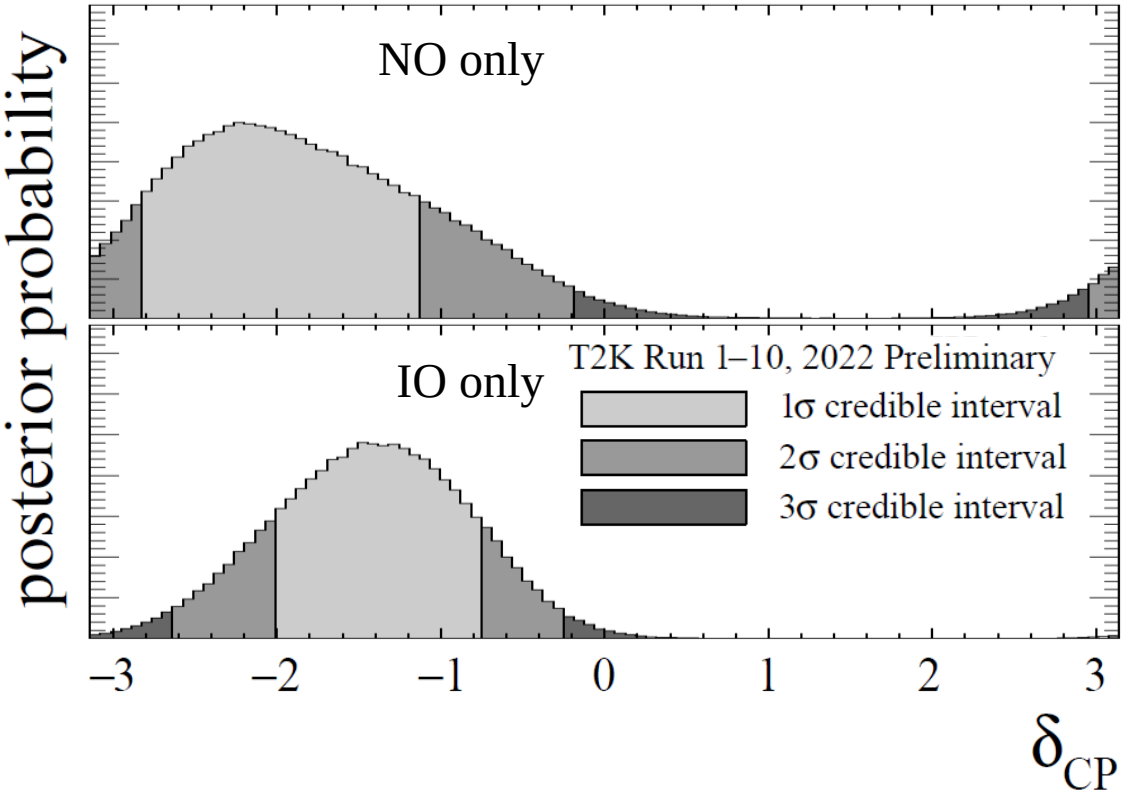
- Search for diffuse SN B/G
- SN watch is now fully automatic
- Early warning from metal-burning stars



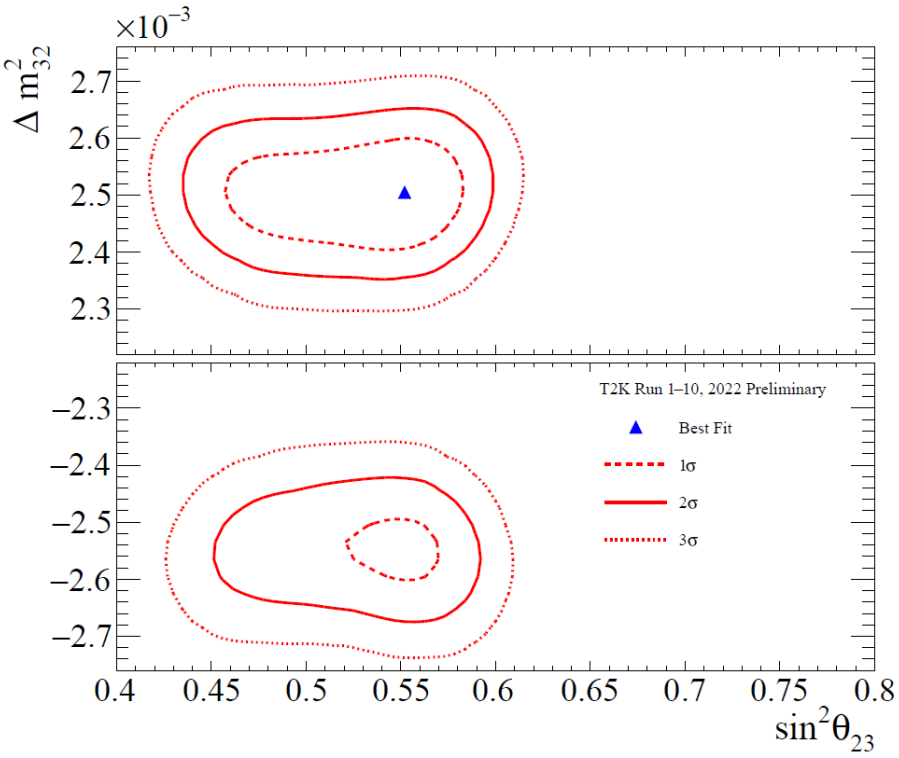


- Neutrinos at 0.6GeV using off-axis beam
- Primary goal (now) is **CP-violation** in $\nu_e / \overline{\nu}_e$ appearance
- Flux × Cross-section directly constrained by **ND280** …
  … but also an **extensive program of interaction measurements** which the margin is to small to contain.
- 'Wrong-sign' background also measured by **magnetised** ND

T2K latest results



	Lower	Upper	Total
NO	0.24	0.39	0.63
IO	0.15	0.22	0.37
Total	0.39	0.61	1.00



Includes a new sample ν_μ with decay $e^\pm$

- Targets $1\pi^+$ events (higher $Q^2 \rightarrow E_\nu$)

Results do not change much, but lower octant is more viable.

T2K upgrades 1

WAGASCI – BabyMIND is already operating

- Measure flux at 1.5° OA & compare ^{16}O to ^{12}C with high ^{16}O fraction

Major Accelerator upgrade of JPARC Main Ring

- Enables faster cycling of magnets → More than double repetition rate
- Larger horn current (more right-sign neutrinos)

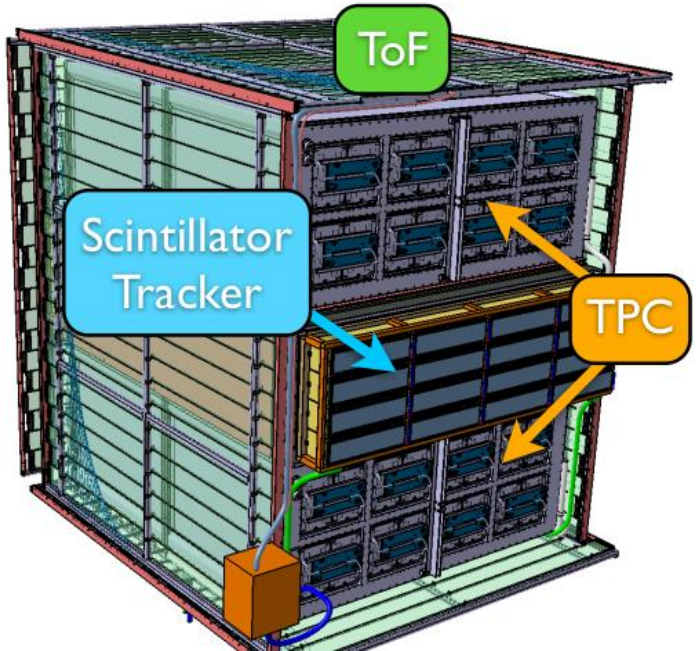
T2K upgrades 2 (ND280)

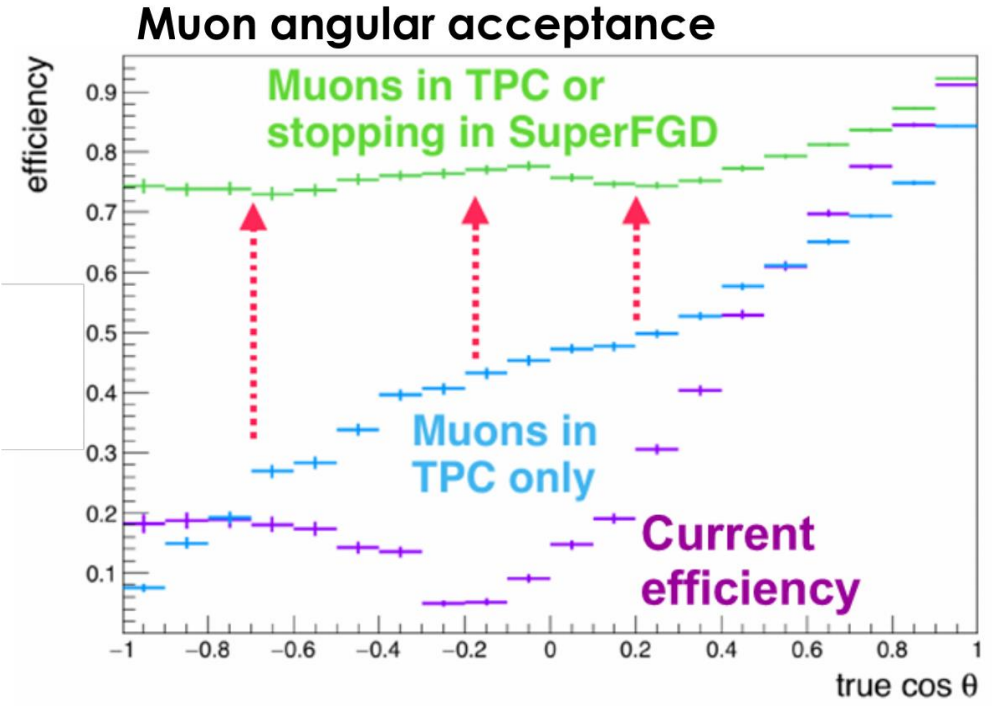
PoD emphasised π^0 measurements in case $\sin^2 2\theta_{13}$ was *really* small

- It turned out to be *really* **large,** so we didn't need the PoD.

Replacement emphasises measurements of inelastic and 2p2h neutrino interactions to improve models

- Low track length thresholds (sFGD)
- High angle reconstruction





T2K joint analyses

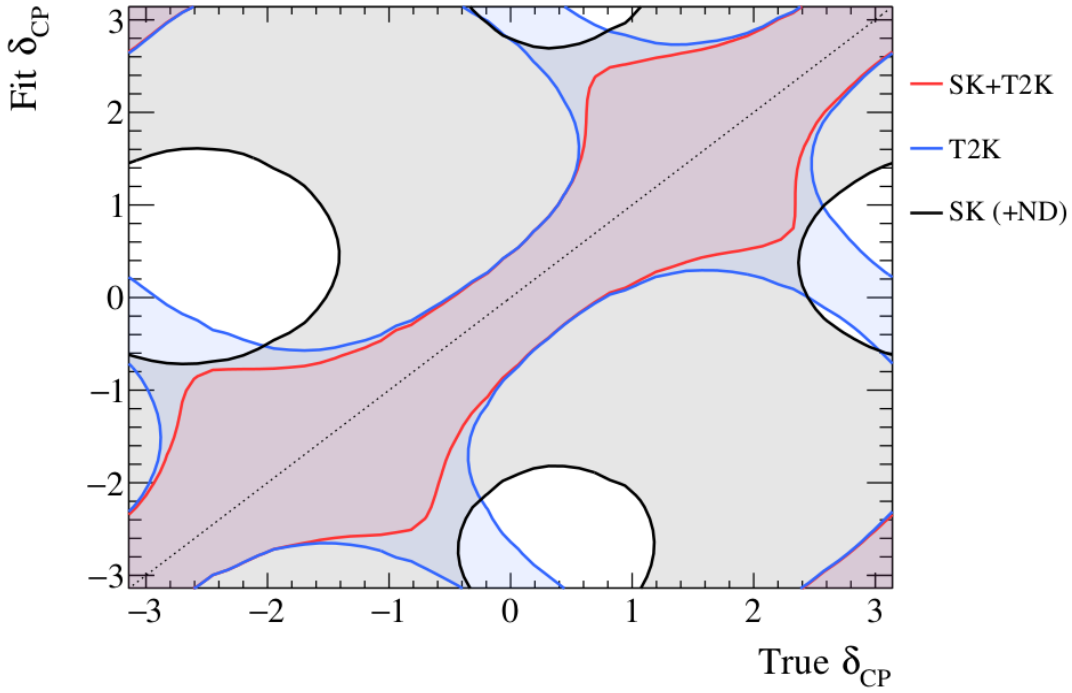
T2K + NOνA already mentioned.

T2K analyses (beam ν) have always been separate from SK (natural ν).

- Joint analysis currently in development

Closer integration than T2K+NOνA:

- Shared interaction models
- Shared detector model
- Unified analysis framework



- Improves MO descrimination (seen)
- **Eliminates $\cos\delta$ – MO degeneracy** of (well-centred) narrow band beam

Future: Hyper-K

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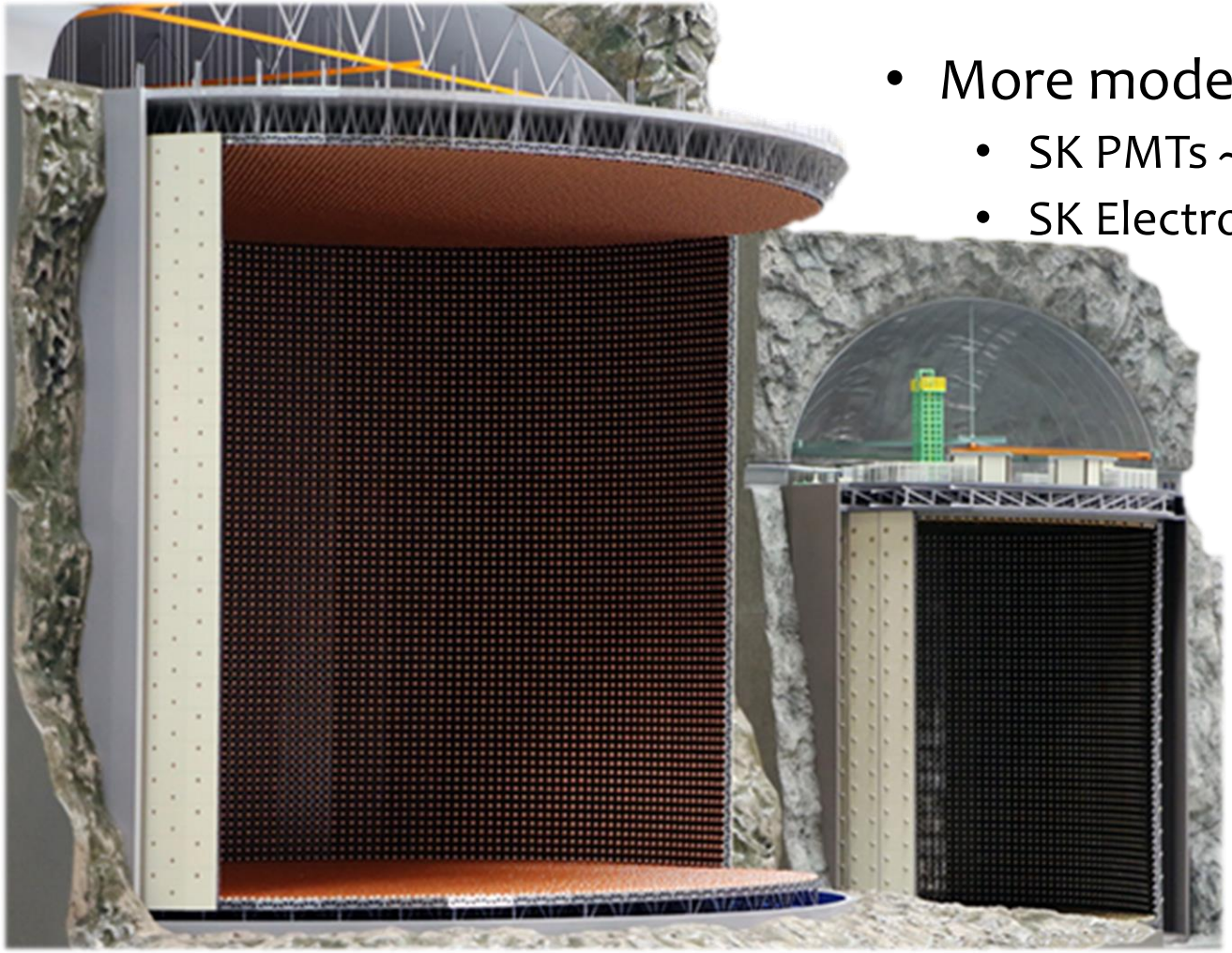
Hyper-K

- New detector with approximately 8 × the fiducial volume of Super-K



- More modern technology:
  - SK PMTs ~30 years old
  - SK Electronics ~20 years old

- Multi-PMT units help understand near-wall reconstruction

- Better calibrations, alignment, radiopurity, …

Hyper-K Project Status

PMT production

2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027

MOU signed, May 2020

Ground-breaking May 2021

Access tunnel complete, Feb 2022

Approach and Peripheral tunnels, Summer 2022

Reached center of cavern, June 2022

Cavern Excavation

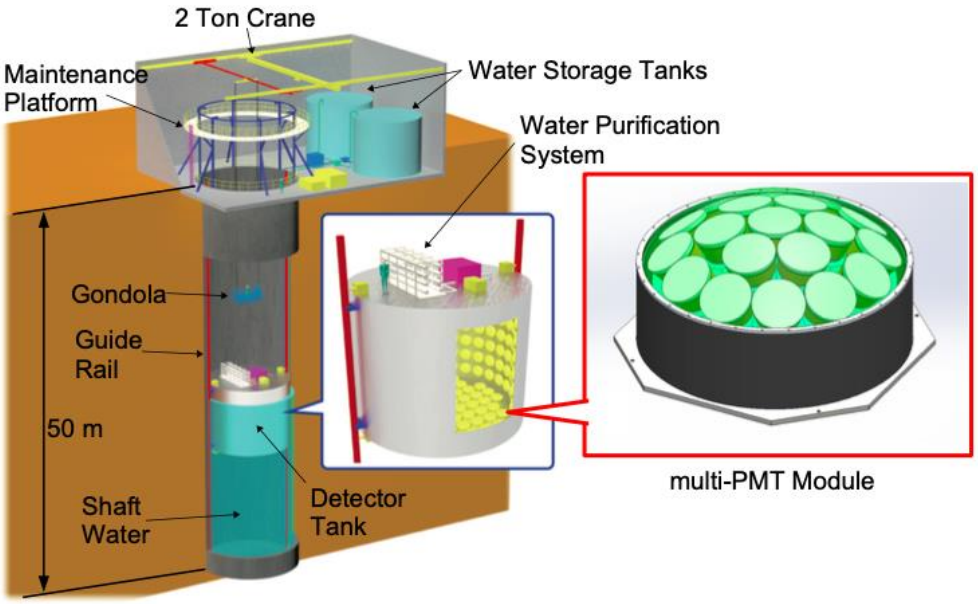
Tank Construction

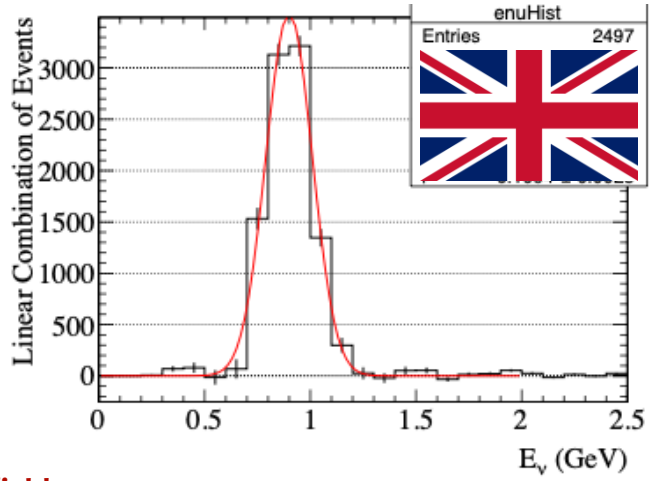
Install'n

Water filling

Operation starts 2027

IWCD





Moving off-axis detector allows you to sample different fluxes

- Can predict off-axis effect well (mostly just geometry)
- Using linear combinations of different angles can effectively create quasi-monoenergetic fluxes.
- Closest thing to a tuneable KDAR sample (except β beam)
- Concept works so well it was shamelessly copied by DUNE…

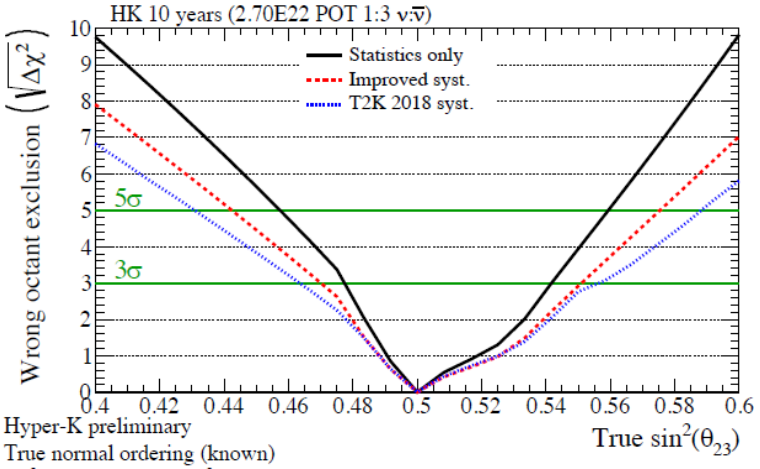
Hyper-K sensitivity

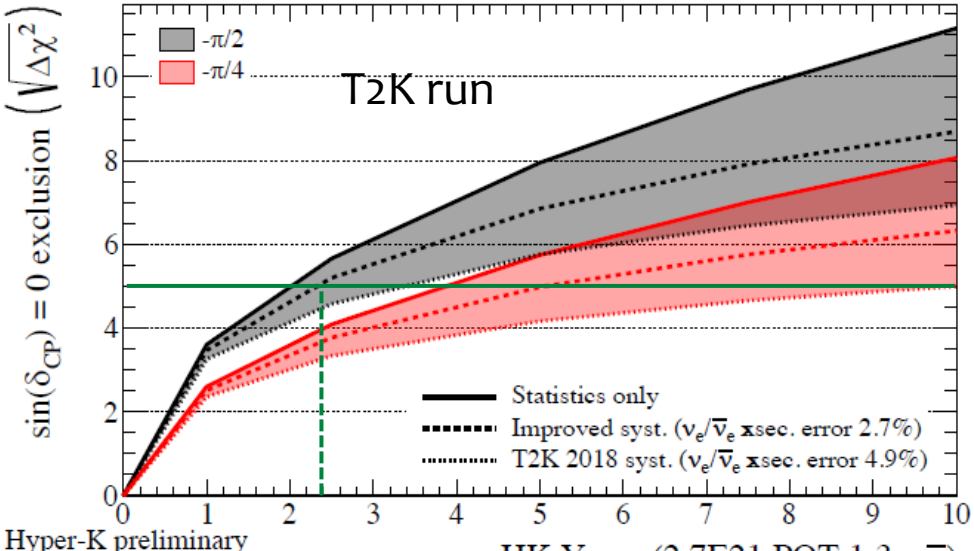
For T2K best fit, Hyper-K may exclude CP conservation at 5σ in <3 years. (!)

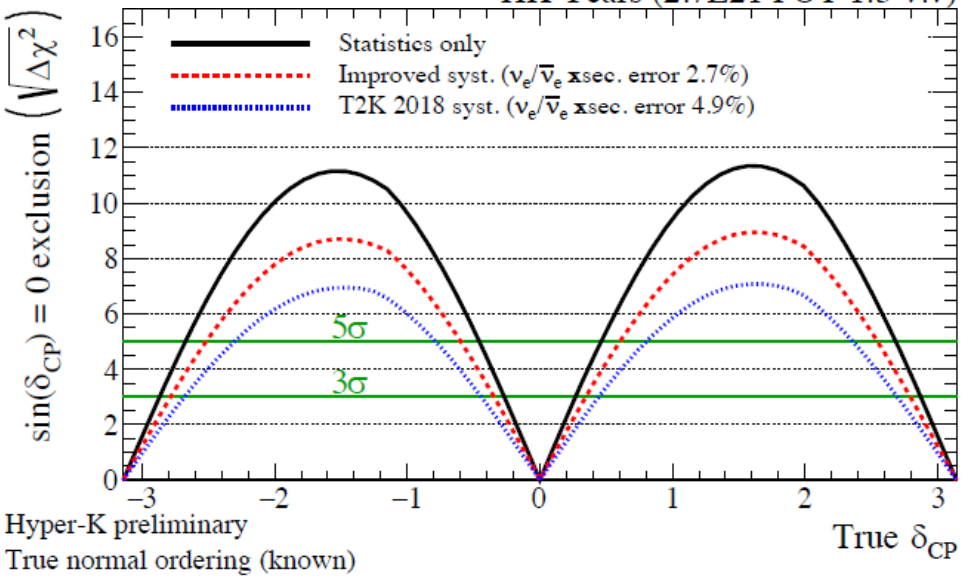
- T2K 90% interval within 10 years

Also after 10 years:

- Error on $\Delta m^2 \sim 0.01 \times 10^{-3} \mathrm{eV}^2$
- Octant resolved at 5σ for:
  $\sin\theta_{23}\{< 0.44\,, > 0.57\}$







University of Glasgow

Hyper-Kamiokande

UK involvement

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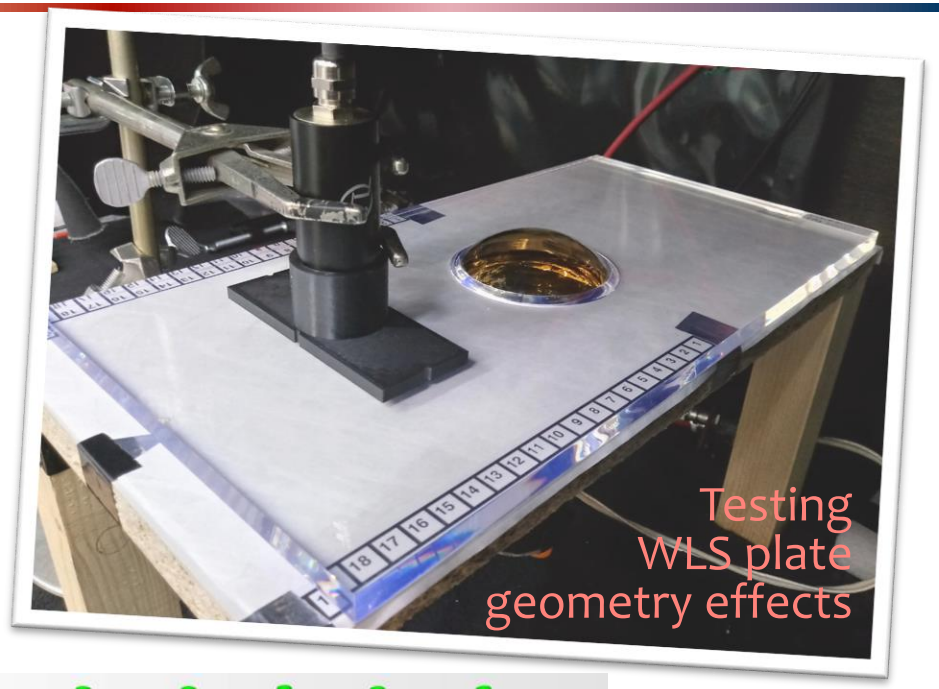
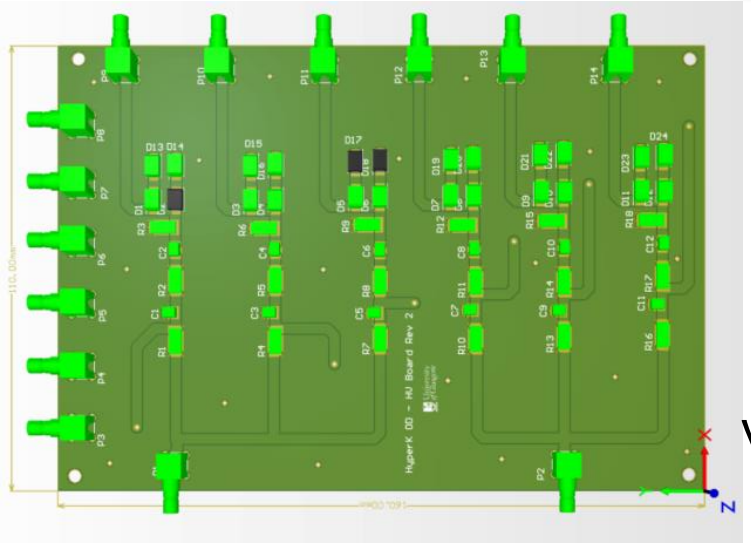
Outer Detector

UK is supplying PMTs and electronics adaptions

- Will use 8cm PMTs with WLS plates
- High-reflectivity Tyvek increases light level substantially over SK
  - Can instrument with less dense PMTs coverage than SK



- Electronics will be shared with ID, but needs a front-end to decouple shared HV circuits and split (DC) HV from fast PMT signals

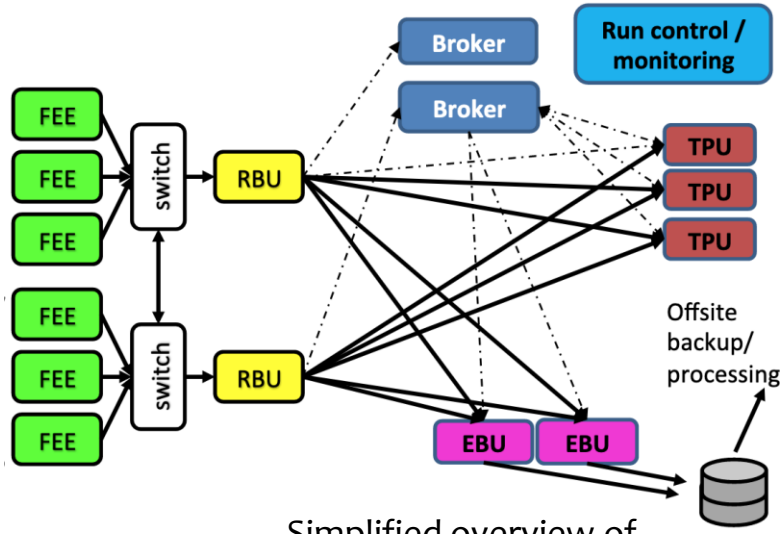


Filter board V2 prototype

Data Acquisition (DAQ) and triggering

DAQ system will

- Read out all digitisations
- Apply (series of) triggers
- Buffer raw data if a supernova happens
- *Be robust and fault tolerant*

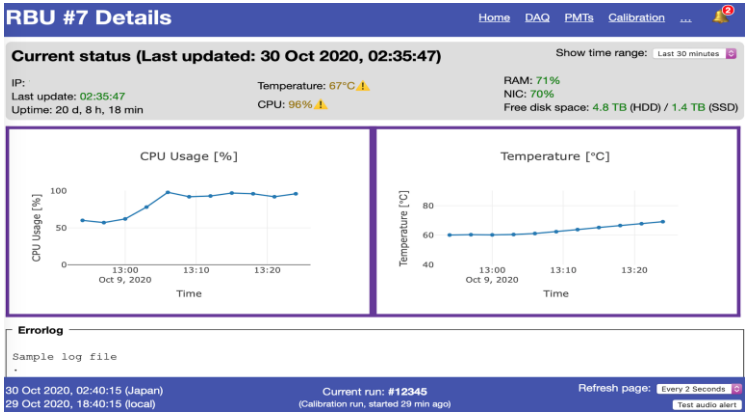


Simplified overview of HK DAQ systems

ToolDAQ framework for DAQ, monitor & triggers.

- Highly parallelised over multiple nodes and GPUs
- Currently testing on UK-based Hyper-K test stand and with simulations
- Trigger performance will also be tested using data from Super-Kamiokande

Monitoring system testing



HK Calibration and QA

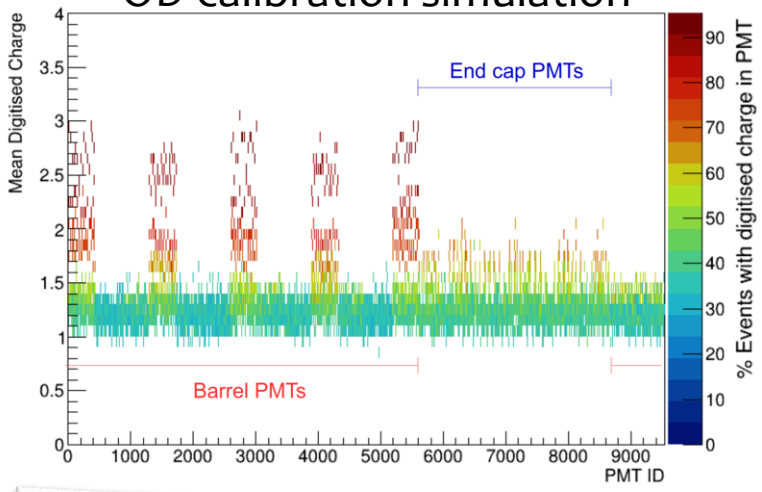
Developing **optical calibration system**

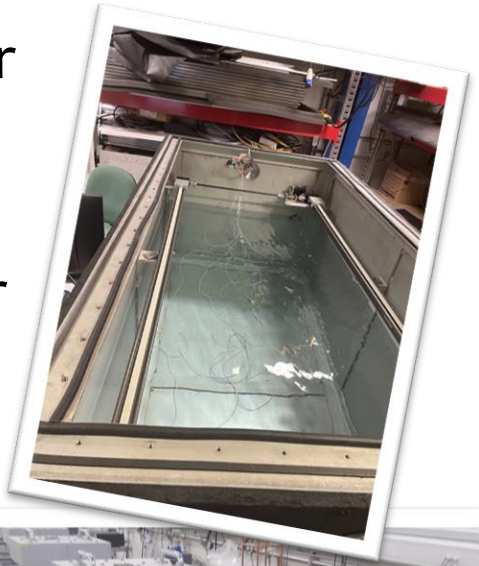
- Multiple light patterns for different tasks
- Currently doing in-water profile measurements for OD system.
- Coverage studies with simulations

Materials testing

- Soak testing in UP- & Gd-Water
- Radon emanation chambers at Boulby

OD calibration simulation





Summary

Neutrino physics in Japan is coming along *fast*!

T2K will be reinvigorated by **upgrades to accelerator power and ND280**.

Hyper-K construction on schedule for 2027 start

- If nature is kind, could discover CPV before 2030!

Also:

- Expect joint analyses from **T2K+SK** and **T2K+NOvA**
- **JSNS²** will be interesting — even if you never believed MiniBooNE/LSND