Physics with Intermediate Water Cherenkov Detector

26 May 2026

6th New Physics Opportunities at Neutrino Facilities Workshop (NPN2026)

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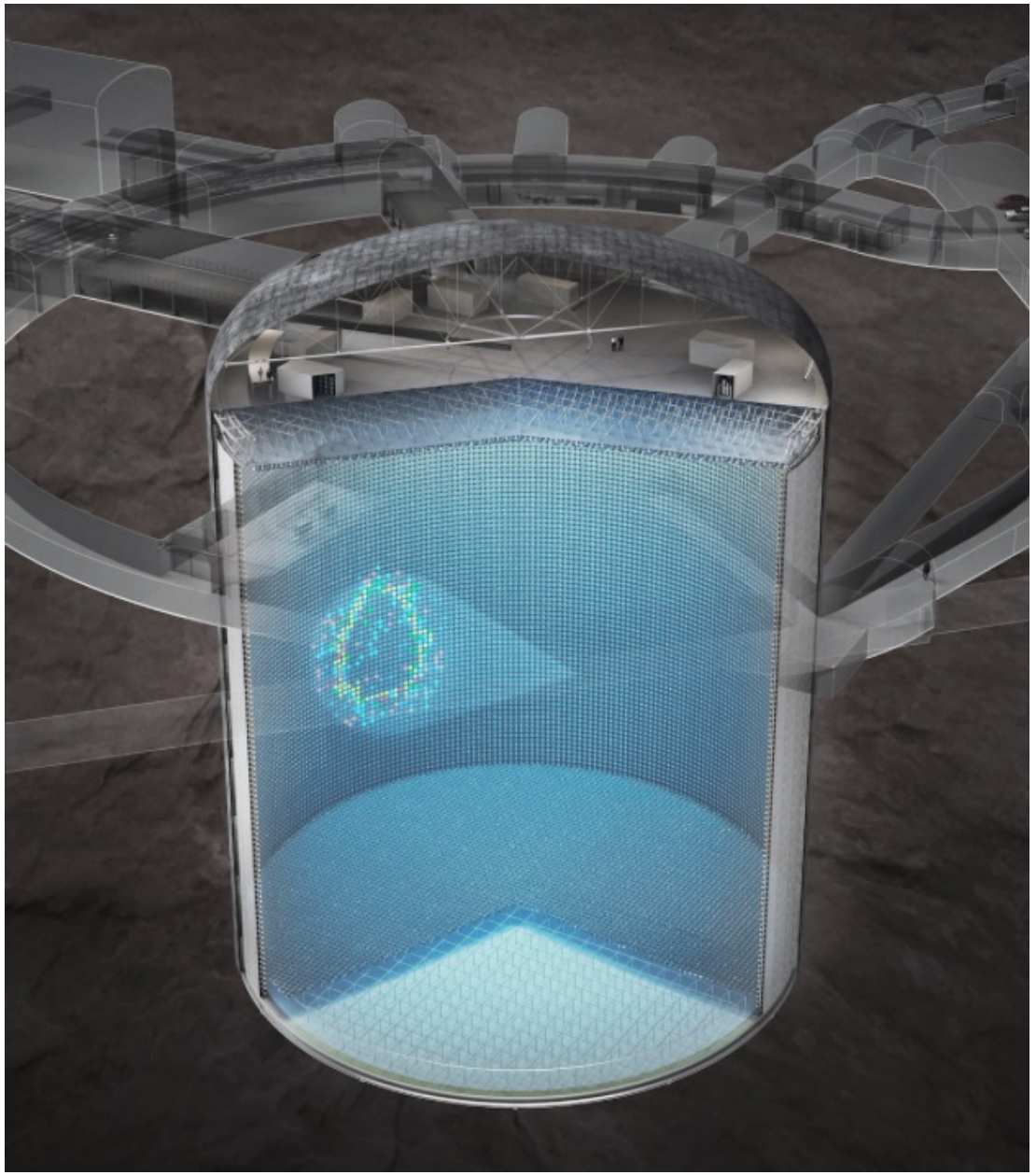
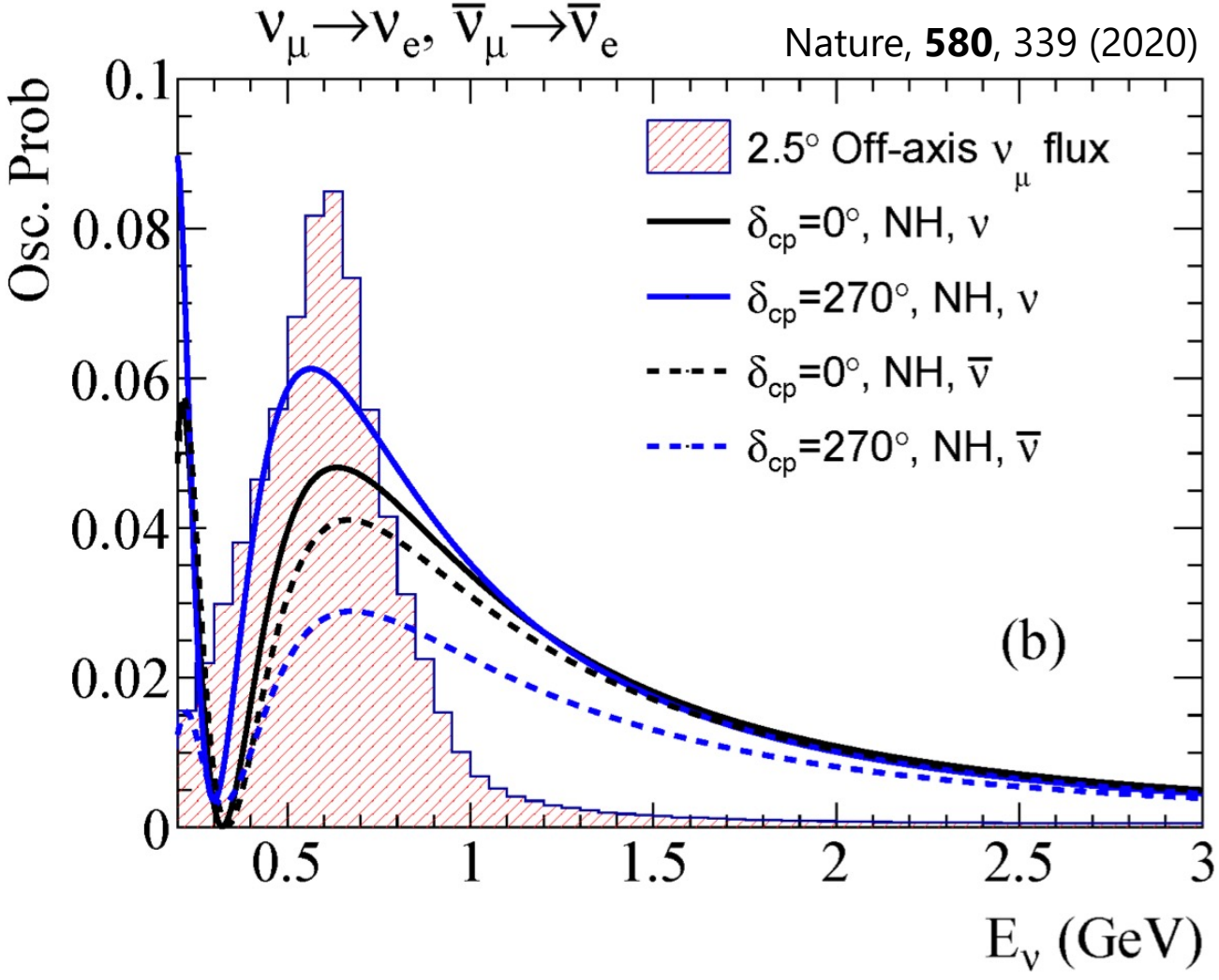
for the Hyper-Kamiokande collaboration



Hyper-Kamiokande

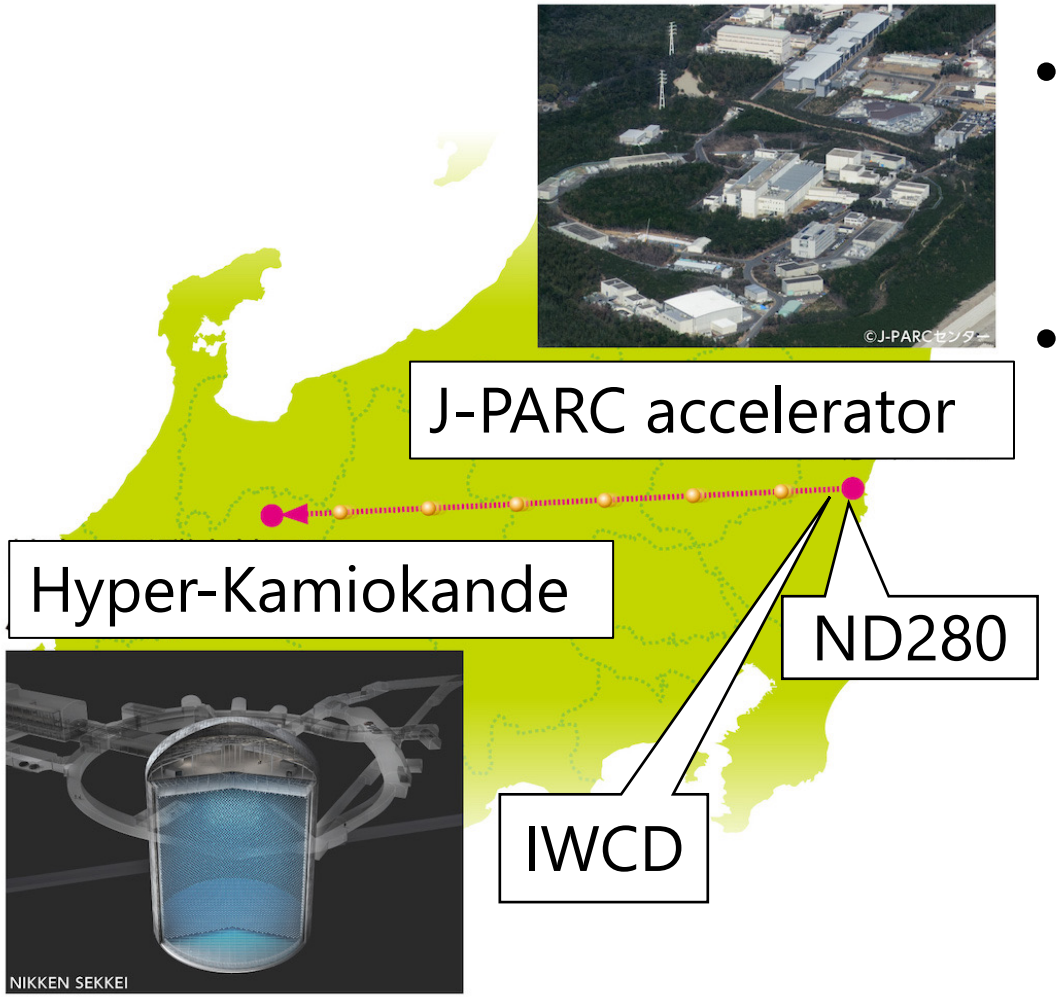
- International collaborative research of the next generation detector
- Several physics:
  - Nucleon decay search
  - Supernova
  - Supernova neutrino background
  - Solar neutrino
  - Atmospheric neutrino
  - Accelerator neutrino
    →Aim to observe CP violation by neutrino and antineutrino oscillation measurement

CP violation in neutrino oscillation



- CP violation is investigated by measuring the difference between neutrino and antineutrino oscillation probabilities
- The T2K measurement excluded the CP conserving values 0 and π at $\sim 3\sigma$

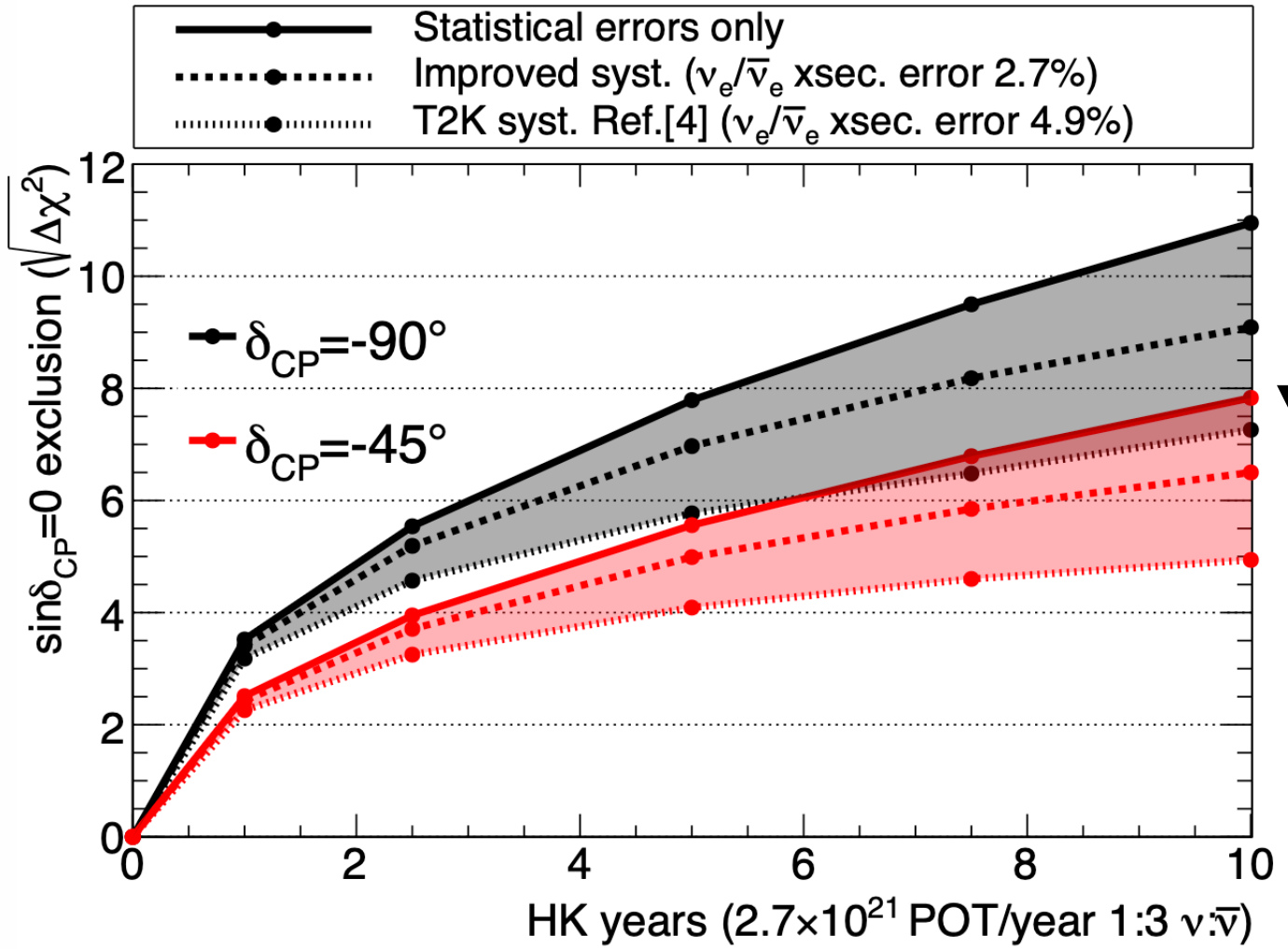
Long-baseline neutrino oscillation experiment



- The oscillation probability is measured by observing the neutrino beam at HK (295 km from the accelerator)
- Larger event rate than T2K:
  - Fiducial volume:
    SK: 22.5kton → HK: 187kton
  - Beam intensity:
    500kW (2019) → 1.3MW

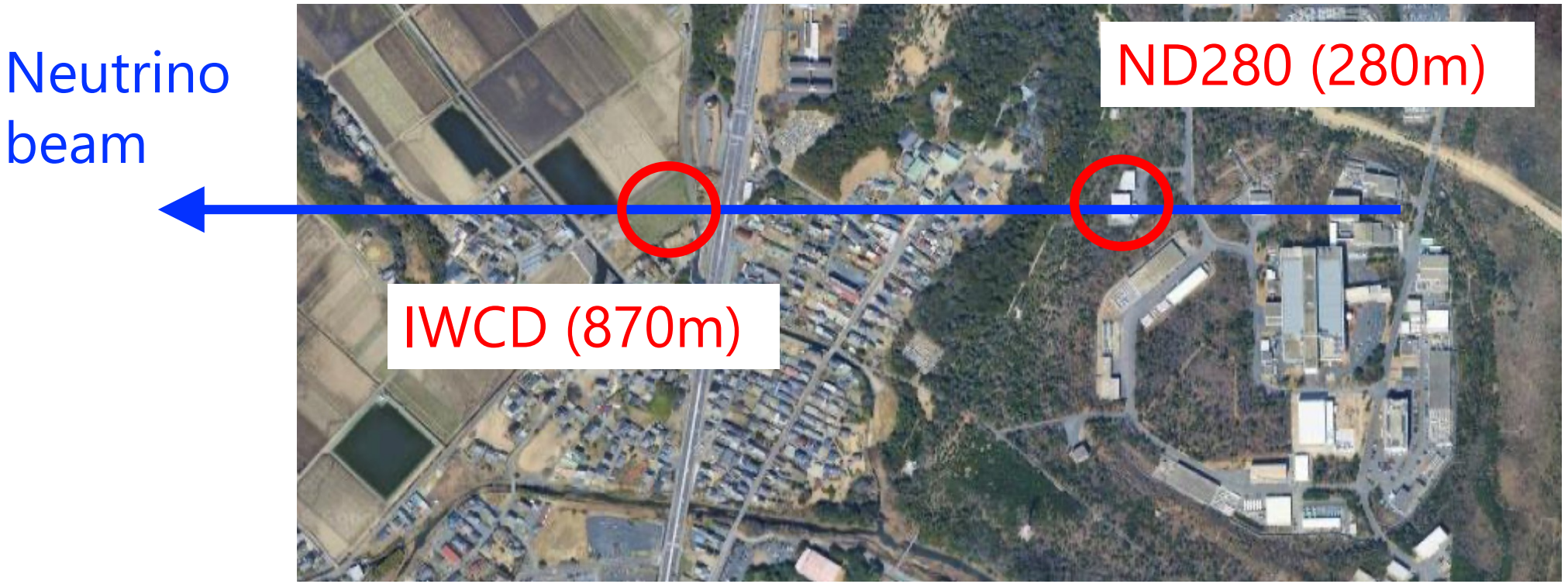
Sensitivity of CP violation

Eur. Phys. J. C **86** 170 (2026)
(Ref. [4] in the figure is Eur. Phys. J. C **83** 782 (2024))



The uncertainty of ν_e/ $\bar{\nu}_e$ cross section affects the precision of CP violation
→ improve in IWCD

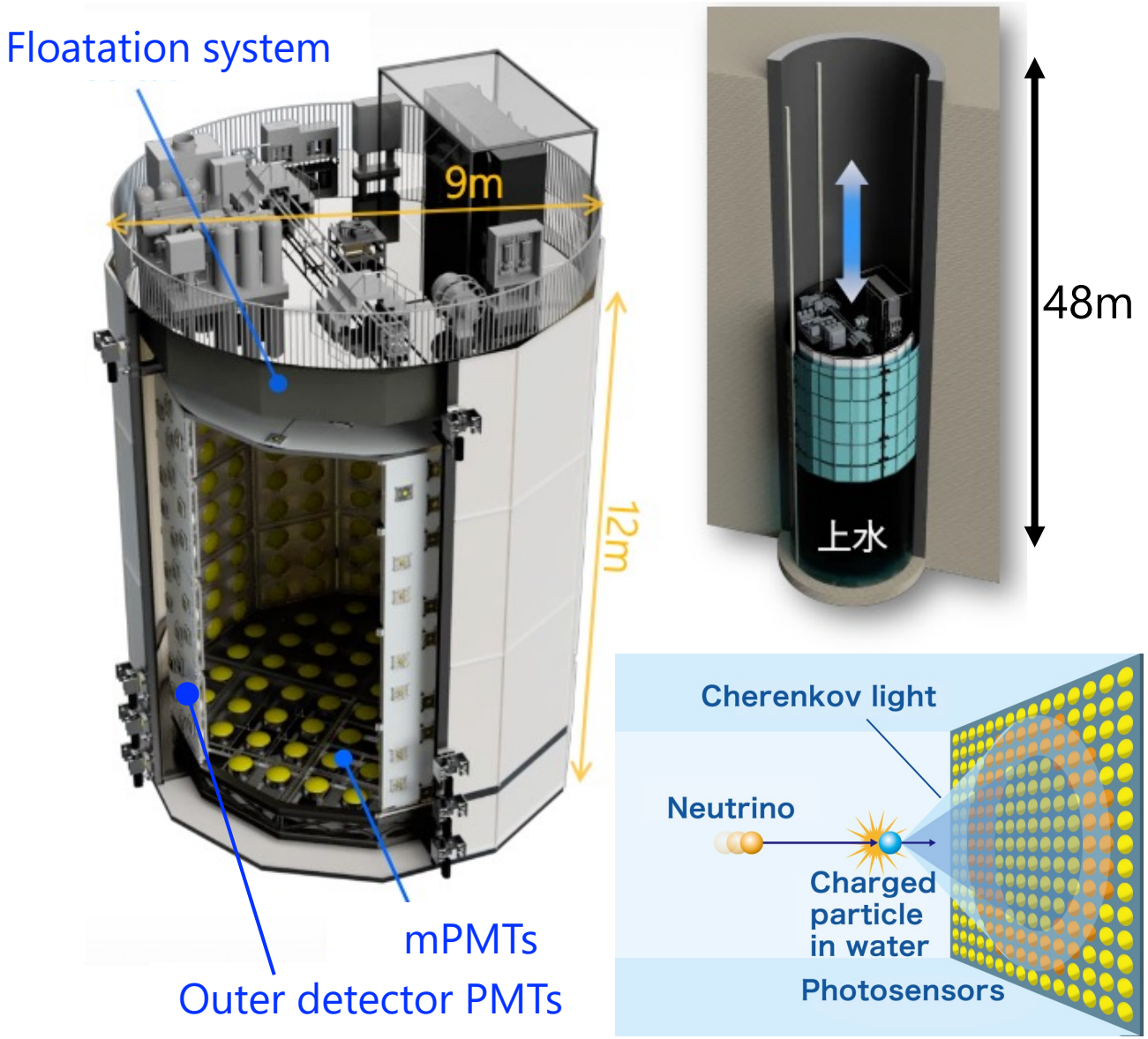
Near detectors of Hyper-Kamiokande



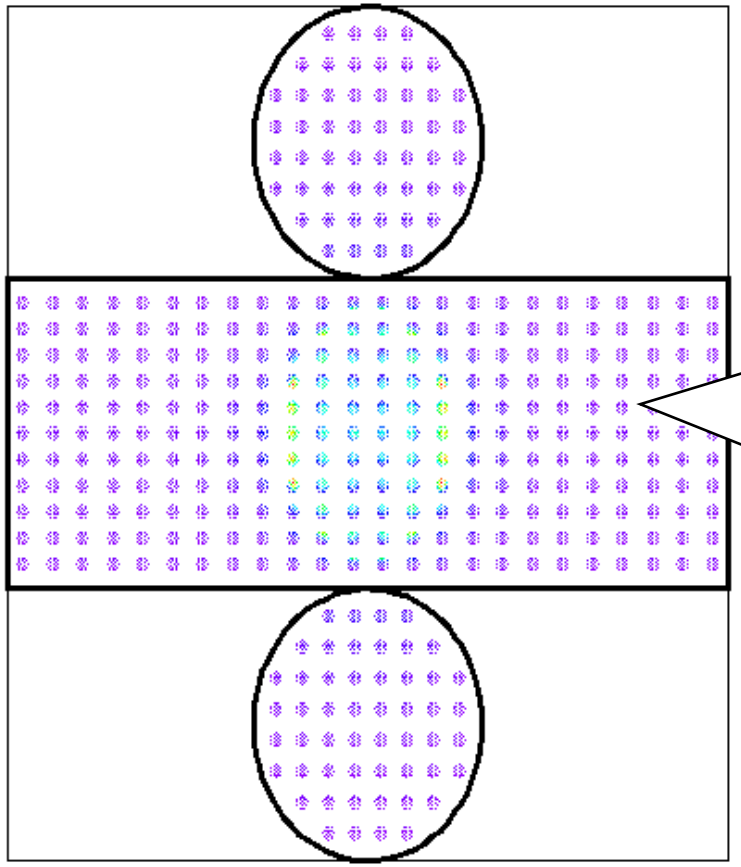
- Reduce systematic uncertainties of the flux and cross section by combining IWCD and ND280

Intermediate Water Cherenkov Detector (IWCD)

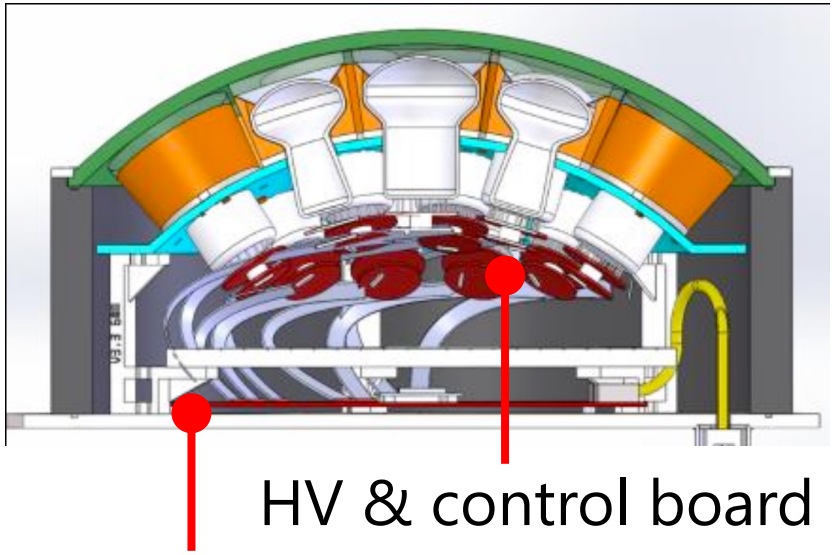
- A near detector of the long baseline experiment
- A 600ton water Cherenkov detector
- Detect neutrinos using the same method as HK
- Vertical movement using the floating module on the top
- New photosensors on the inner wall （mPMT)



An example of electron event

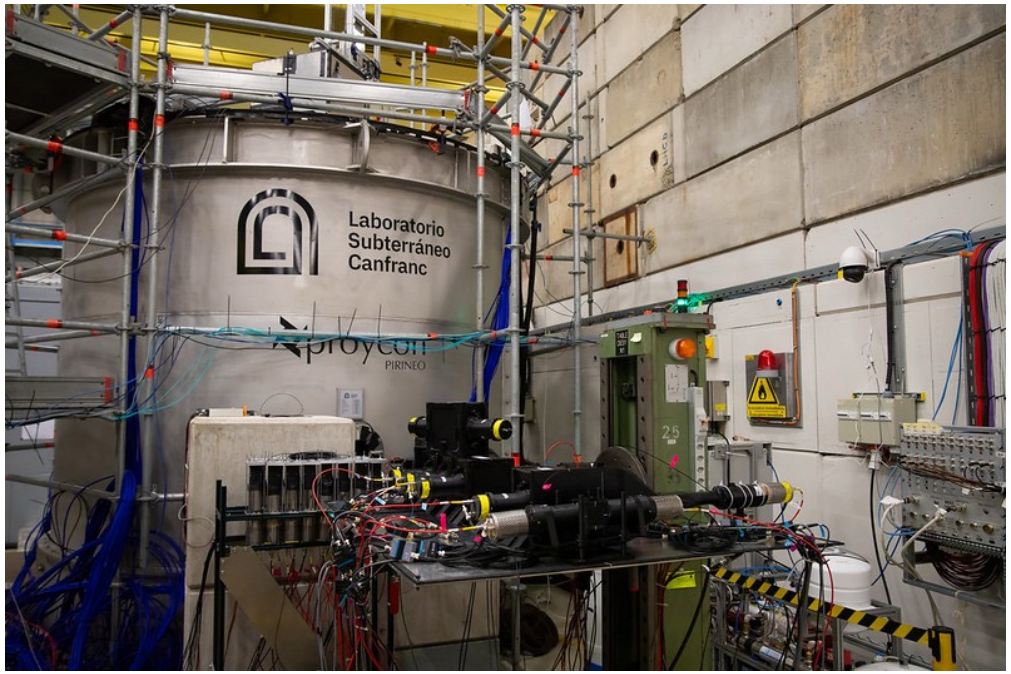


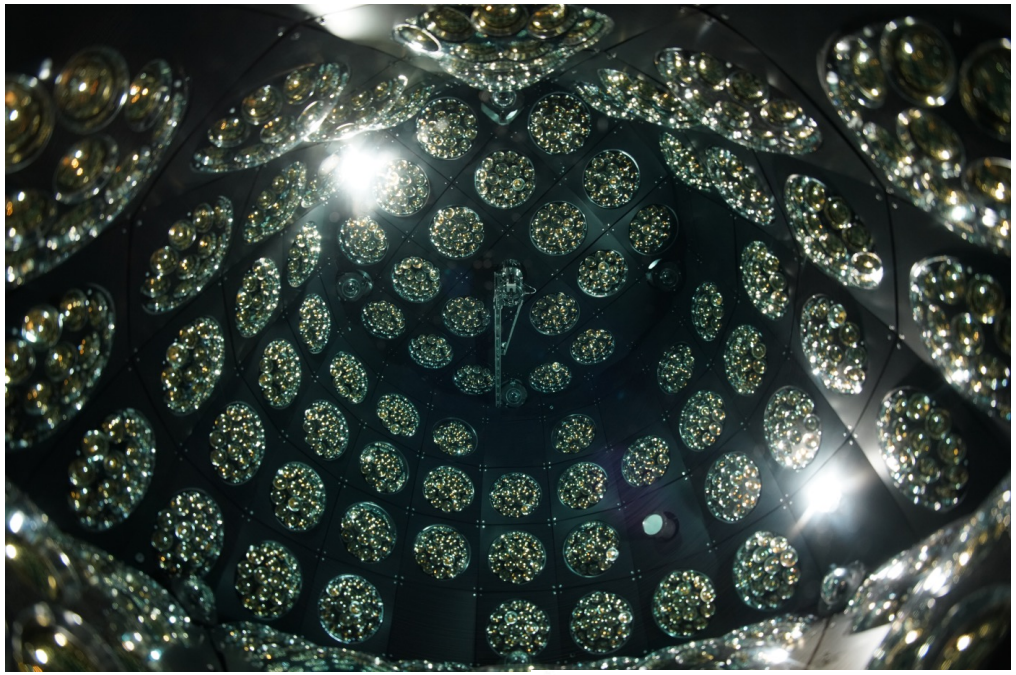
multi-PMT



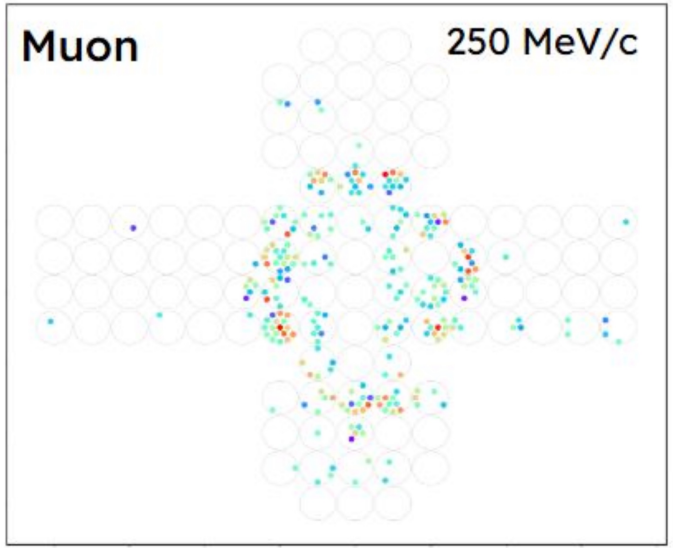
- mPMT consists of 19 PMTs (8cm diameter) in a 50cm diameter vessel
- 368 mPMTs on the ID wall
- High resolution and directional sensitivity to incoming photons
- They will be used in HK in addition to the 50cm PMTs

Water Cherenkov Test Experiment



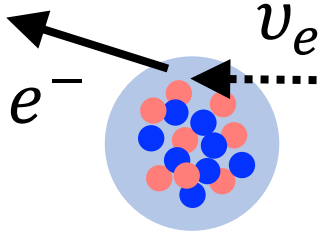


- Test new technology used in IWCD
  - mPMTs, calibration and water system
- Small size (~3m) detector at CERN (~2025)
- Physics analyses using accelerator beam data are also ongoing

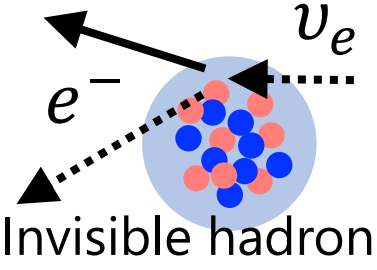


υ_e $(\bar{\upsilon}_e)$ cross section at IWCD

- HK observes υ_e $(\bar{\upsilon}_e)$ CCQE events around 0.6GeV
  → IWCD measure υ_e $(\bar{\upsilon}_e)$ events using the intrinsic flux (~1%) from muon and kaon decays
- At IWCD, True high energy events make a sizable contribution to 0.6GeV region as non-QE events (feed-down)

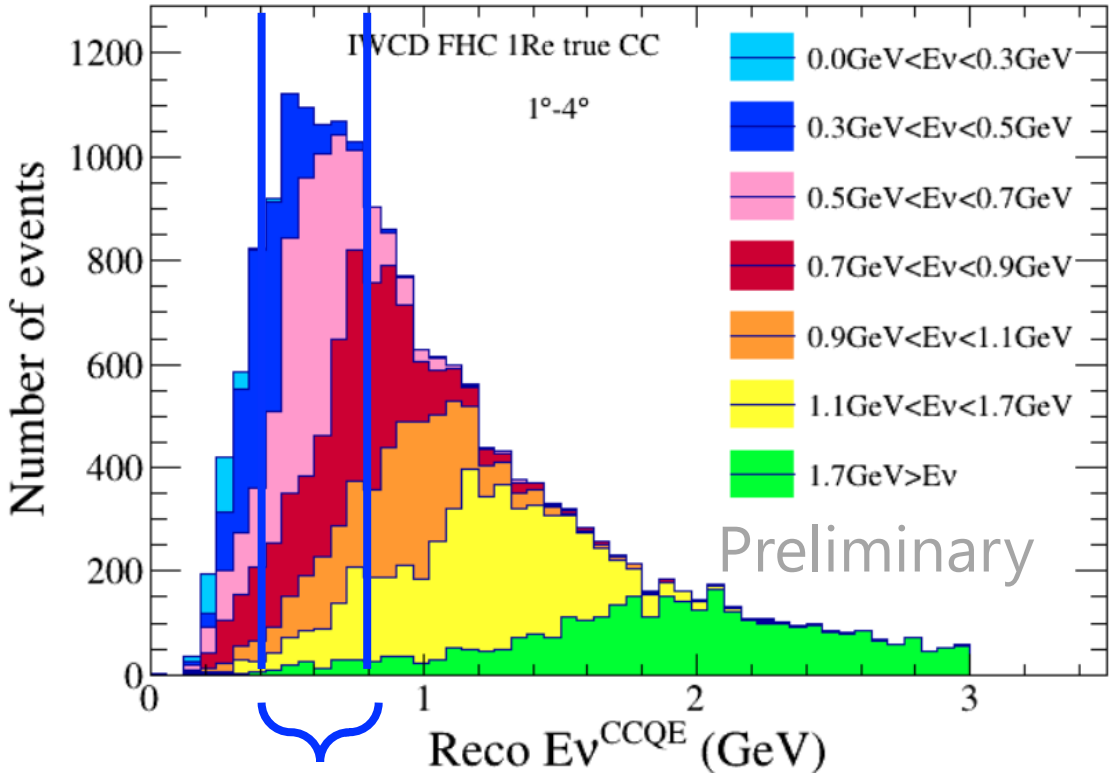


CCQE events



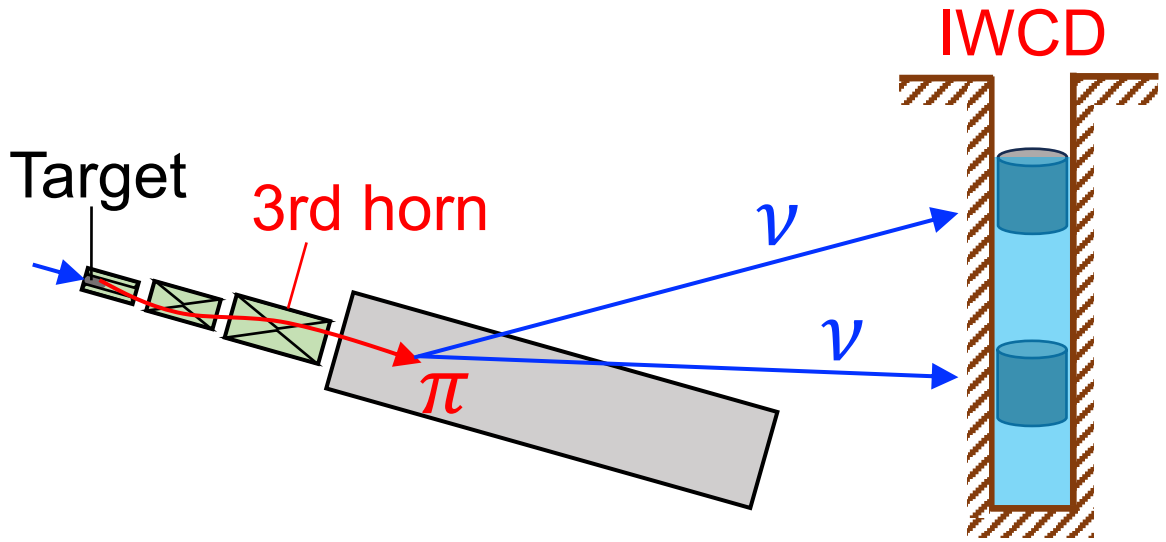
BG by non-QE

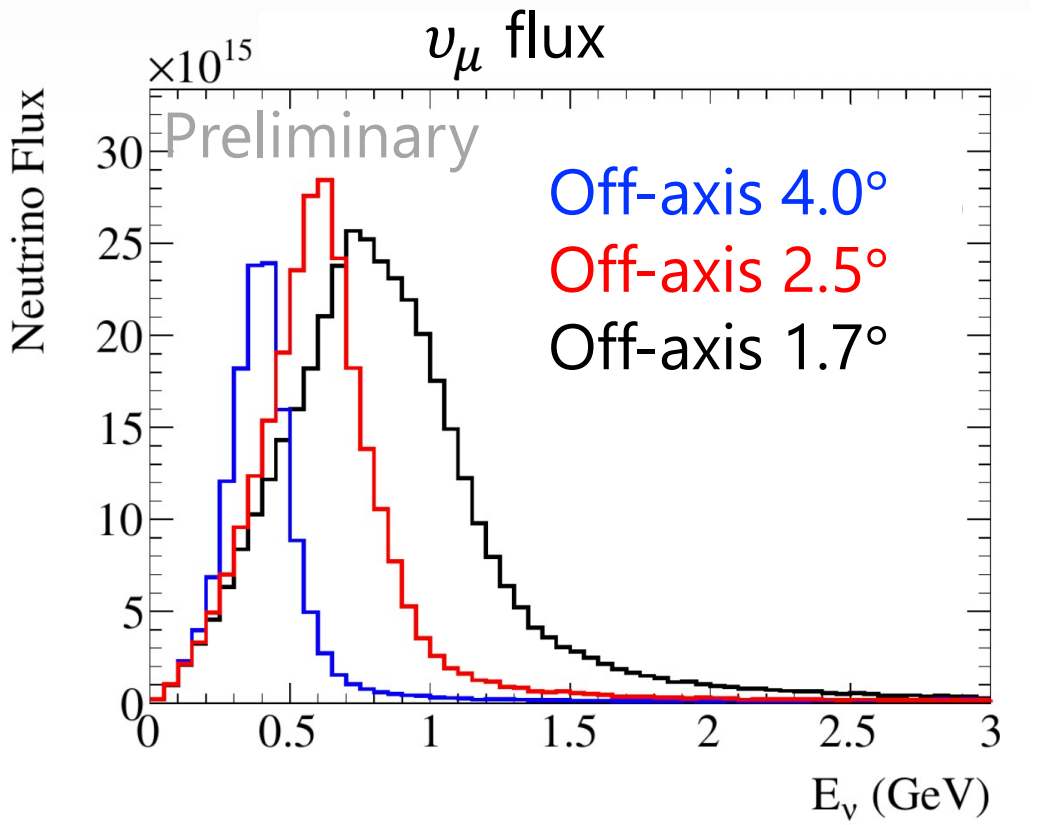
Reconstructed energy of υ_e events at IWCD



Oscillation probability peak around 0.4~0.8GeV

Off-axis scan

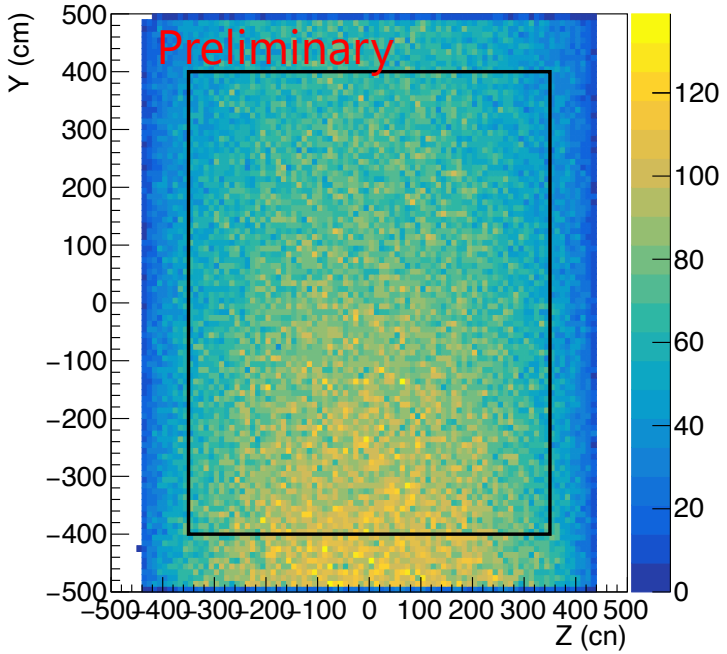




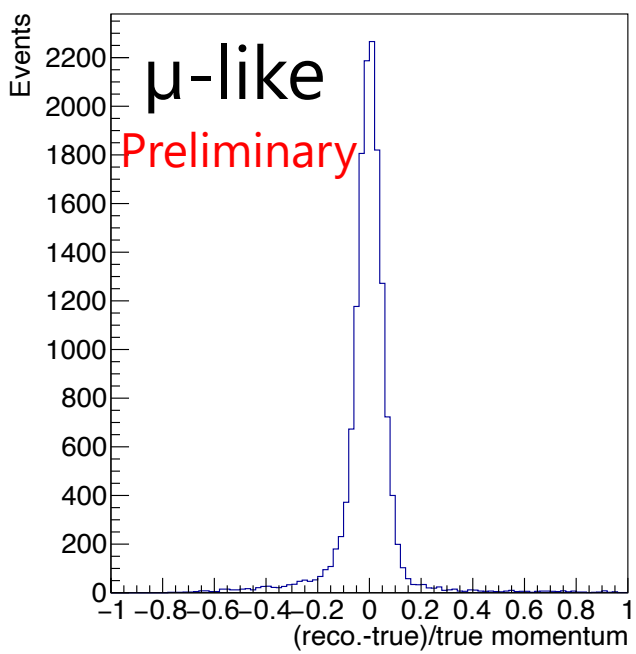
- Neutrino flux depends on the angle from the beam axis (off-axis)
- Off-axis scan gives several energy spectra
  → Different non-QE event contributions constrain the feed-down from high energy
- Aim to measure υ_e /$\bar{\upsilon}_e$cross section in ~3% precision

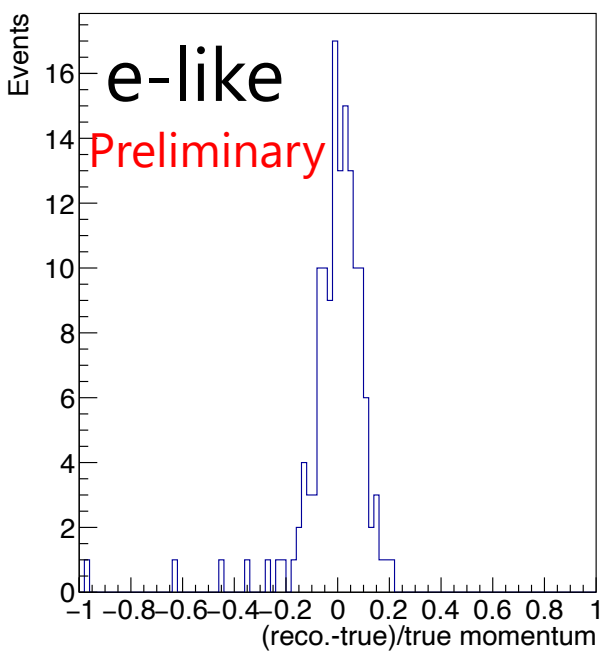
IWCD simulation

- Validating the event simulation and reconstruction algorithm with a small-scale sample
- Plan to increase the sample statistics and evaluate the expected sensitivity to the cross section



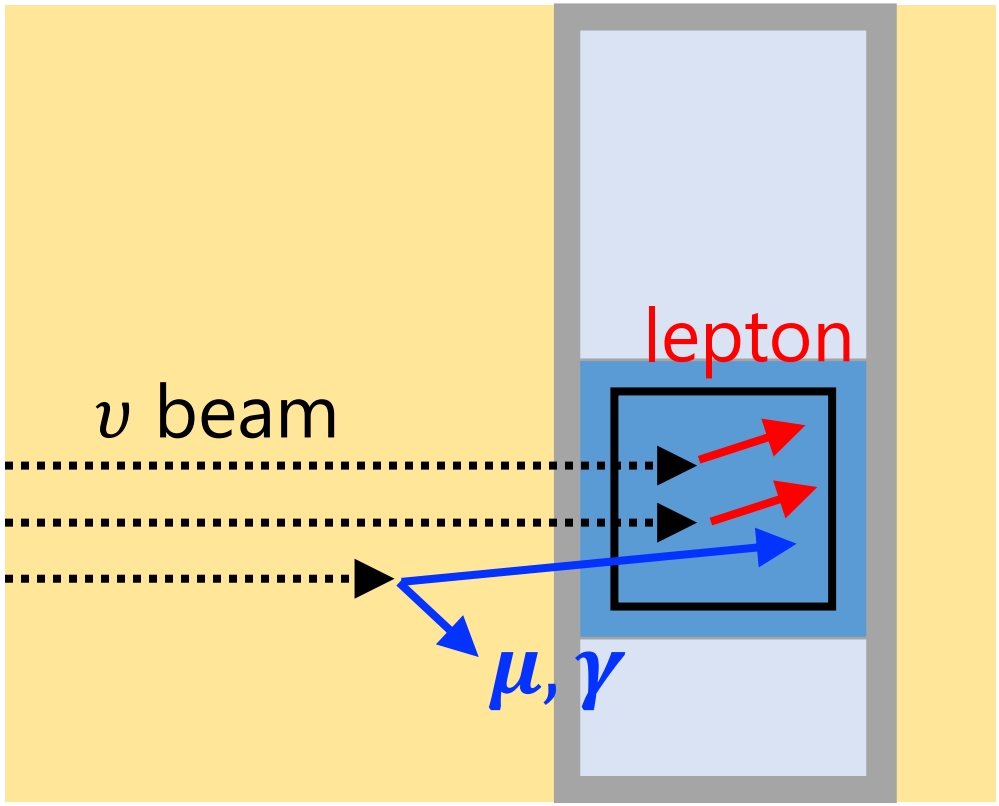
Neutrino beam vertex

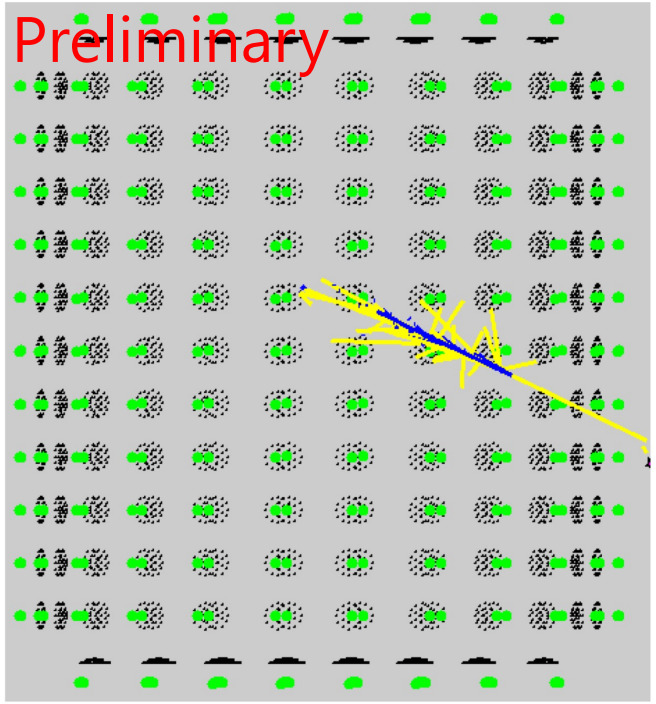




Momentum reconstruction performance

Pile-up events



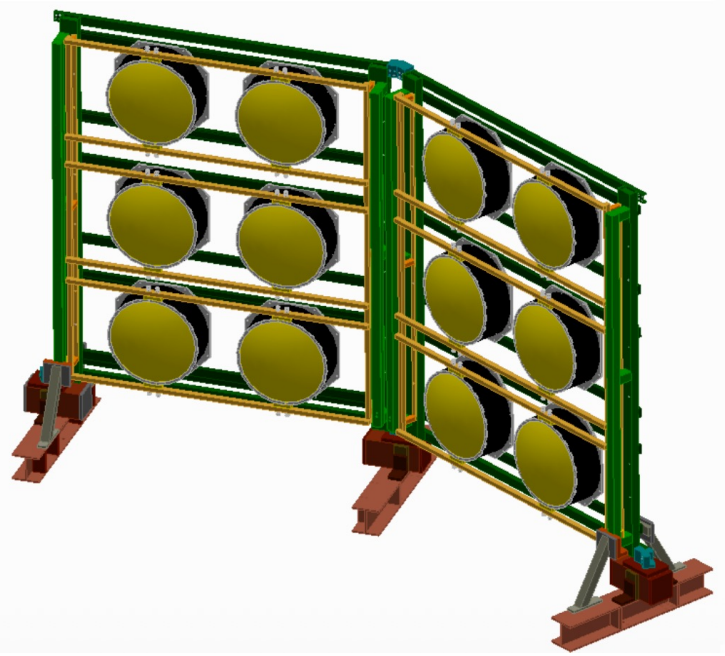


mPMT
OD PMT
gamma
electron

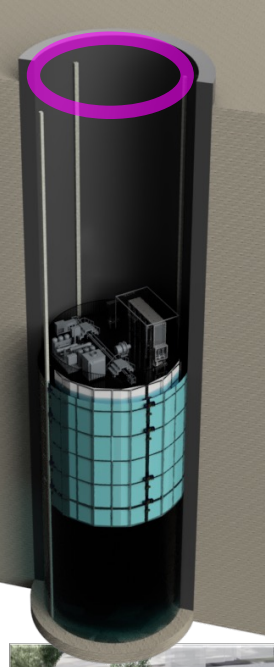
An example of event that are difficult to identify as an entering particle using OD
→ need ID information to identify

- Since IWCD is the near detector, pile-up events are expected
  - Multiple neutrinos interact in the inner detector
  - Neutrinos interact in the sand or concrete and enter the tank
- Evaluation of the reduction by the outer detector and development of the identification algorithm is ongoing

Mockup test at J-PARC

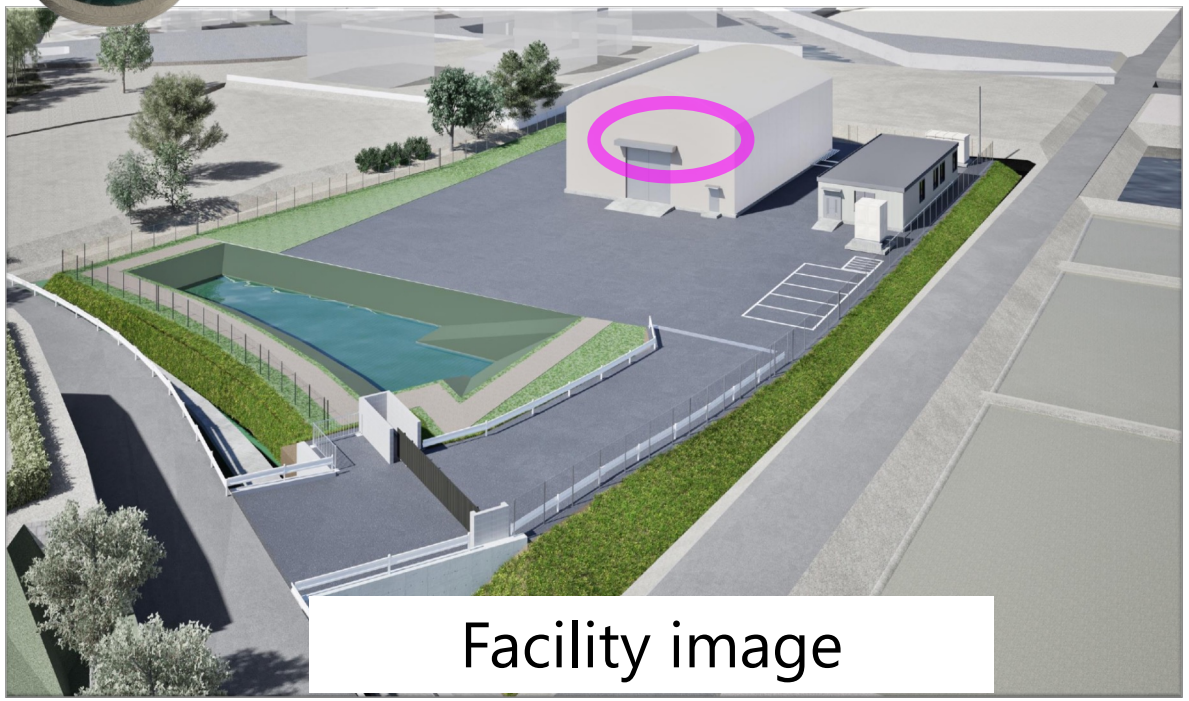


- The basic support structure consists of 6 mPMTs (and OD PMTs)
- Test for the design of the PMT support structure and establishment of the assembly procedure

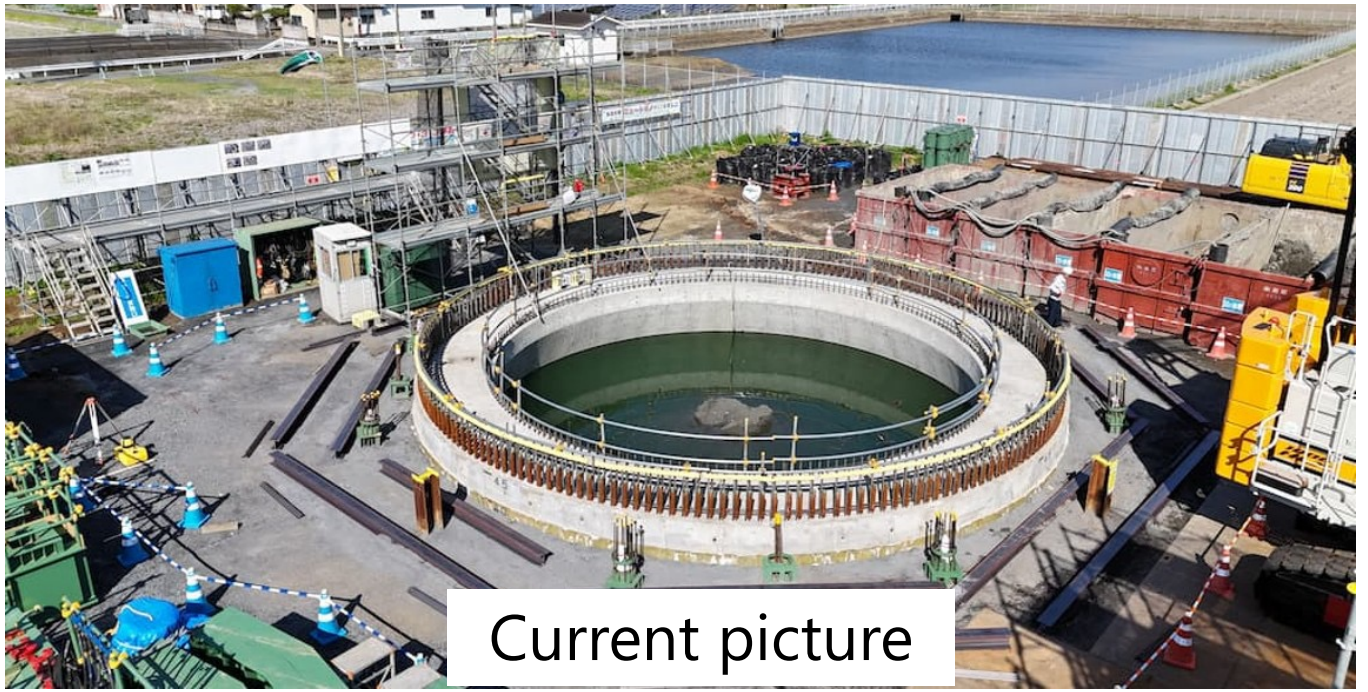


Construction

- The shaft excavation work is currently in progress
- Detector assembly work is planned upon completion of the excavation work



Facility image



Current picture

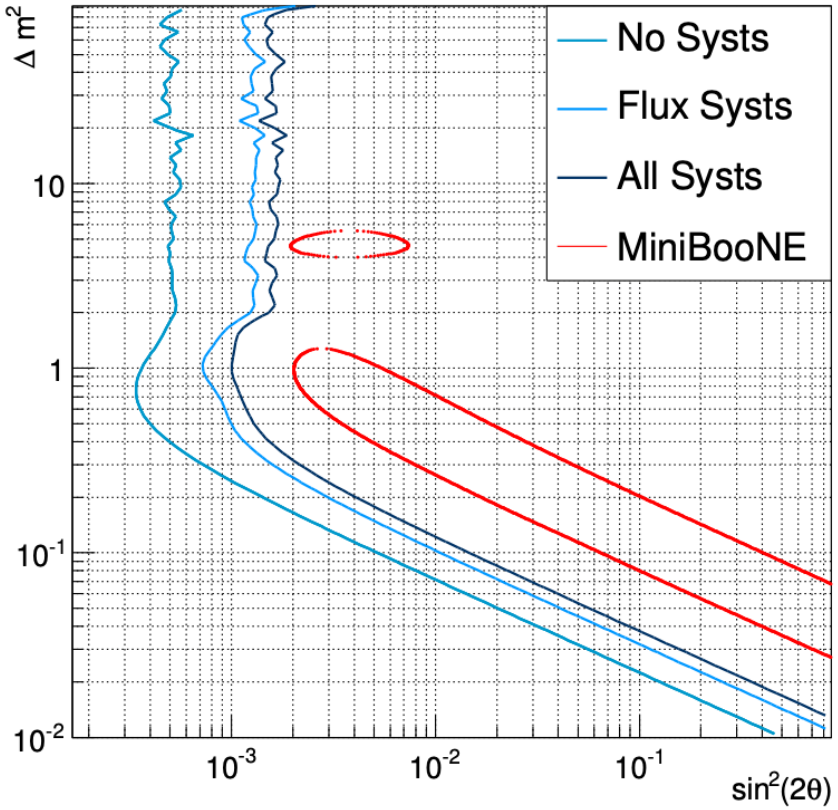
Summary

- Accelerator neutrino observations at Hyper-Kamiokande aim to achieve sensitivity to the discovery of CP violation with larger event rate than T2K
- Reduce uncertainties of the flux and cross section by the new near detector IWCD
  - The same target and observation method as HK
  - Off-axis scan
- The shaft excavation work has been underway since 2025
- Simulation studies, detector testing are also in progress
- Planning to start the neutrino beam observation with HK in 2028

Backup

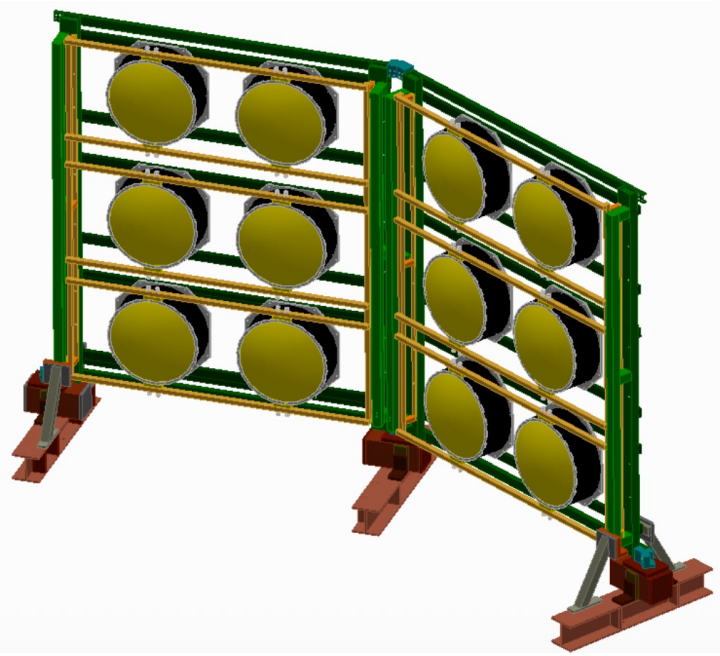
Expected sensitivity

Bhadra, S et al, arXiv:1412.3086 (2014)



- 90% C.L. for 4.6×10^{20} p.o.t. (ID radius 4m)
- For reference since the detector position and design have changed

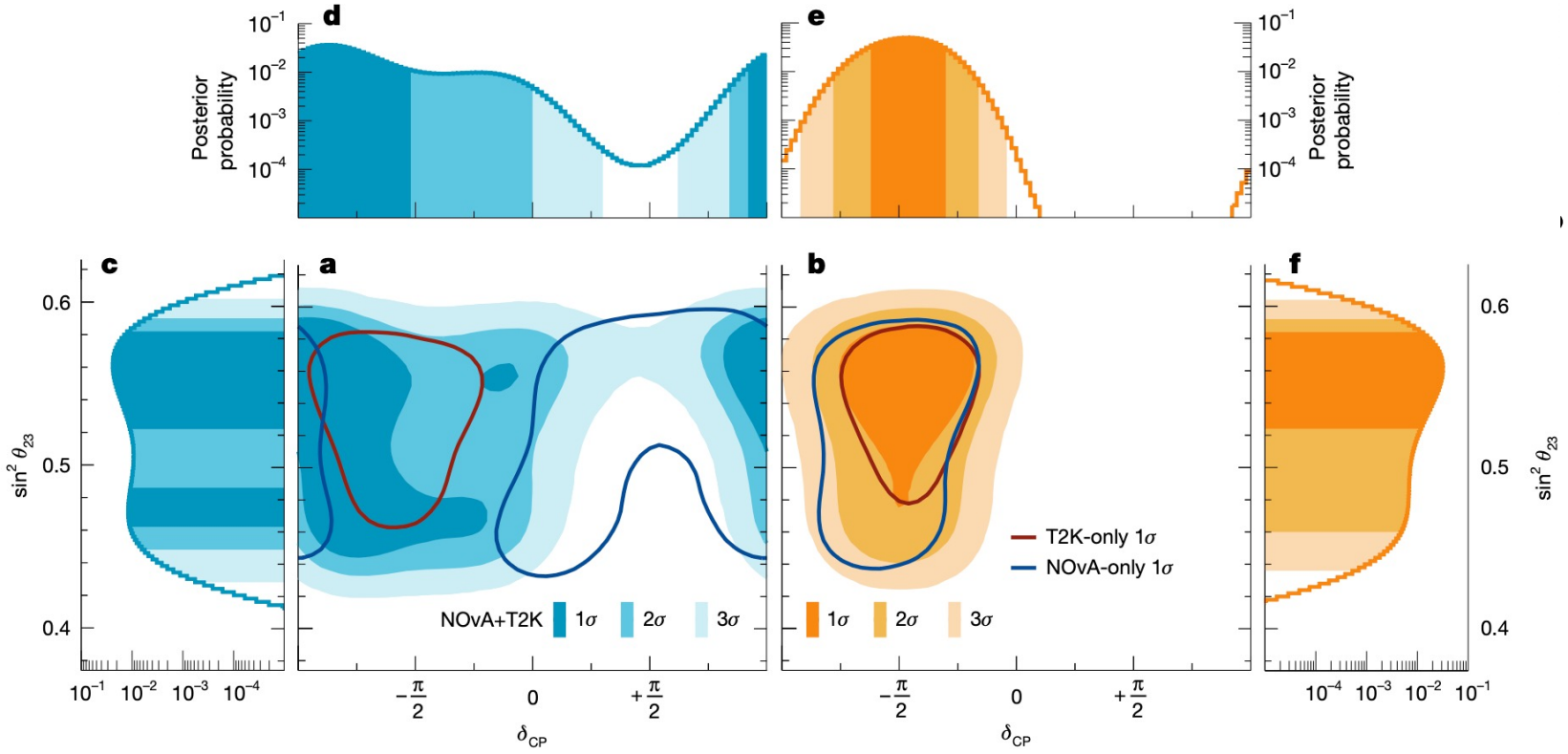
Mockup test at J-PARC




- We conducted a mock-up test to obtain feedback on the support structure design for the optical sensors and to establish the assembly procedure
- Currently, the design work for the actual equipment is underway with a engineering company

Joint analysis T2K + NOvA

Nature **646**, 818 (2025)



- $3\,\sigma$ interval on δ_{CP}
  - NO: $[-1.38\,\pi, 0.30\,\pi]$
  - IO: $[-0.92\,\pi, -0.04\,\pi]$