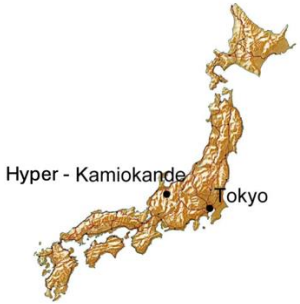
Hyper Kamiokande status and French contributions IRN neutrino 2025

Lorenzo Restrepo Orrantia (on behalf of HyperK-France)

Physics program

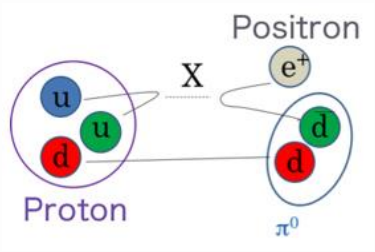
HyperK physics program

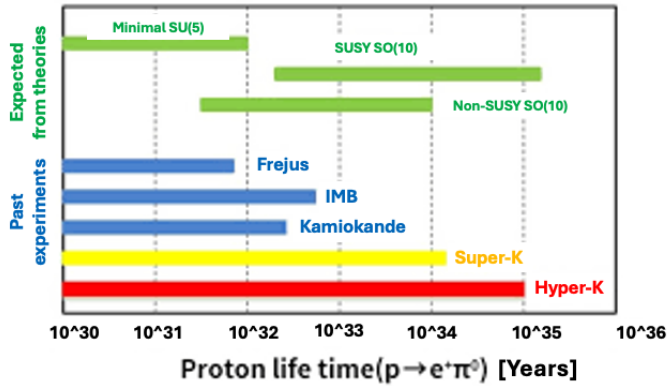
- 3rd generation water Cherenkov detector in Kamioka, Japan



Kamiokande (1983) → V x 22.5 → Super-Kamiokande (1996) → V x 8 → Hyper-Kamiokande (2028)

✓ Nucleon Decay Experiment





✓ World-leading sensitivity

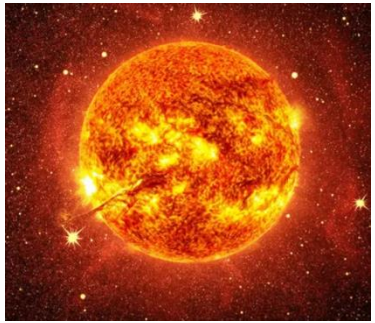
(After 10 years of data)

✓ Neutrino Detection Experiment → Which kind of neutrinos?

HyperK physics program

Neutrino program

Solar neutrinos



- ^{8}B spectrum
- Day-night asymmetry

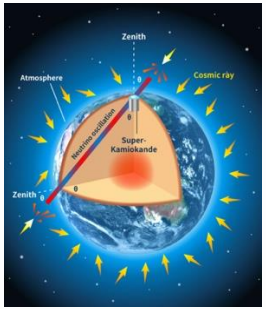
Baseline neutrinos

- J-PARC accelerator
- World-leading measurements of θ_{23}, Δm^2_{23}, δ_{CP}

Supernova neutrinos

- Around 10^5 events expected for a galactic SN
- Model discrimination

Atmospheric neutrinos

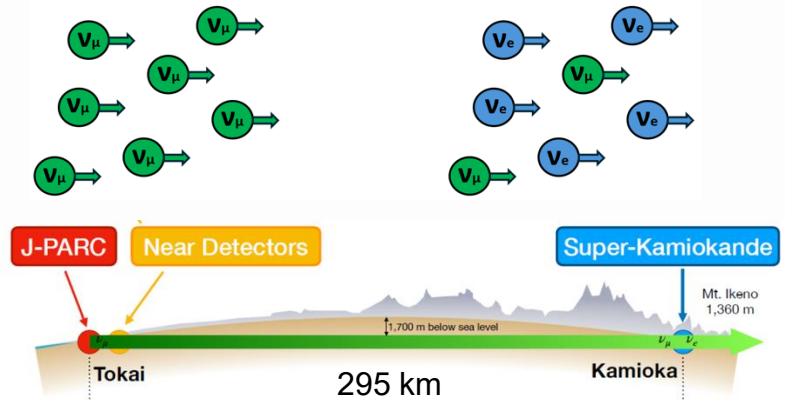


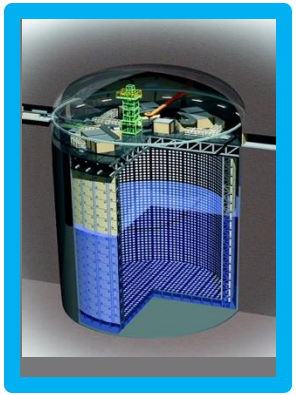
- Complement to the baseline program
- Mass hierarchy

About the Long Baseline program

(See Pierre's talk!)

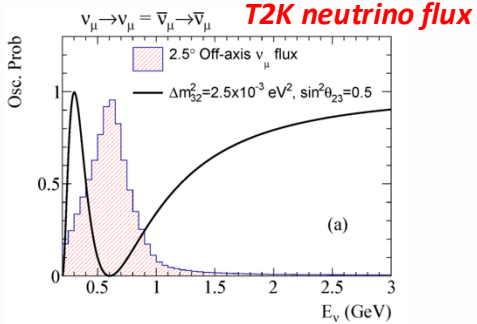
- HK will use the same neutrino beamline of the T2K experiment





Near detectors:

- Ingrid
- ND280
- IWCD



Water Cherenkov detector (2.5 degrees off axis):

- Now SuperK
- Soon HyperK

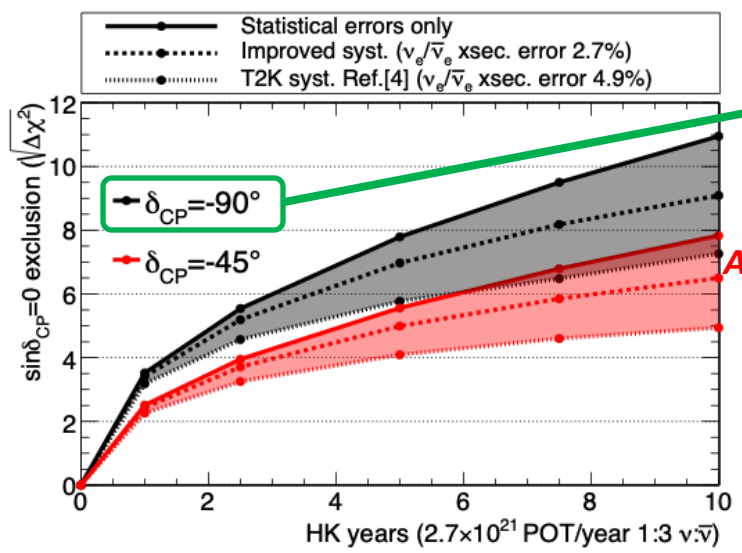
About the Long Baseline program

- **Primary goal**: measure CPV in the lepton sector (i.e. $\delta_{CP} \neq 0$)

Potential CPV discovery in only 3 years with HK !

Other goals: provide the most precise measurements of :

- ✓ θ_{23} (Octant degeneracy)
- ✓ Δm^2_{23}



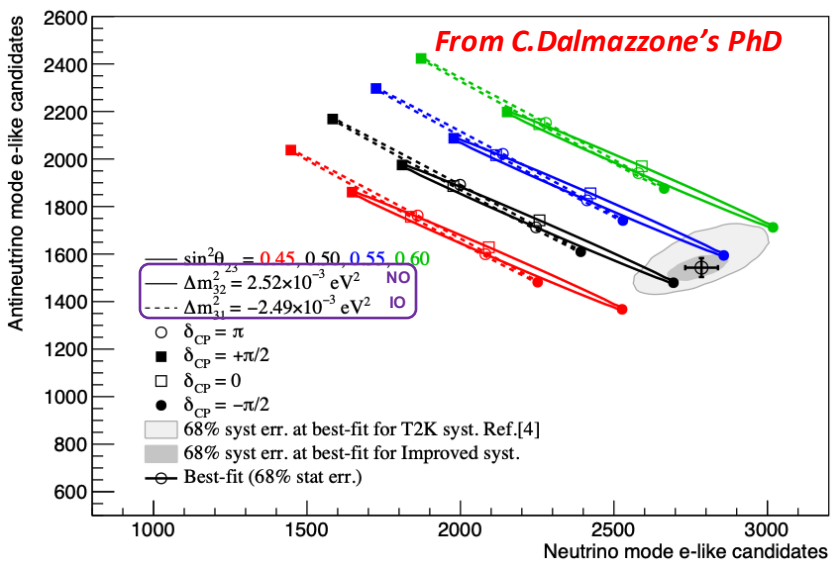
Current T2K best-fit

Accepted for publication in EPJC

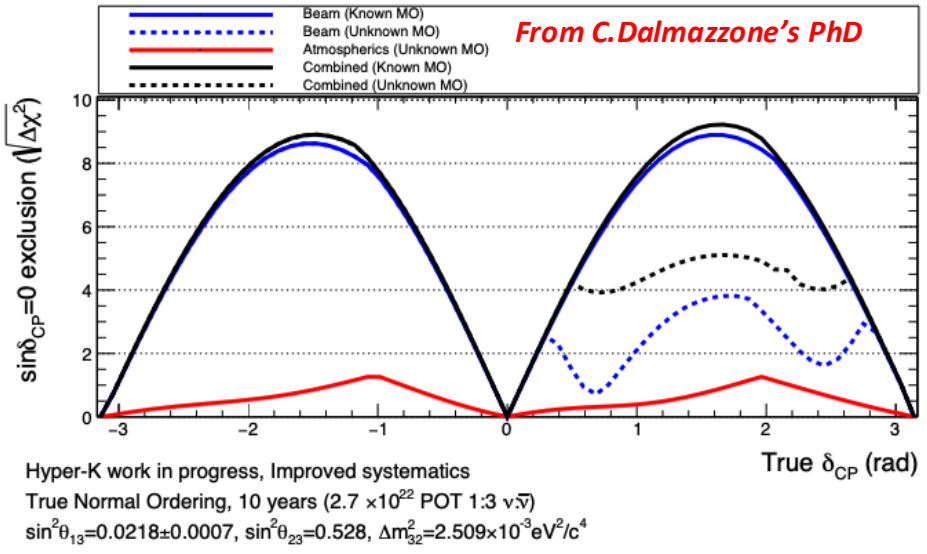
"Sensitivity of the Hyper-Kamiokande experiment to neutrino oscillation parameters using accelerator neutrinos" arXiv:2505.15019

Combined analysis baseline + atmospheric

Expected $\overline{\nu}_e$ vs ν_e with 10 years of HK



Combined analysis with 10 years of HK



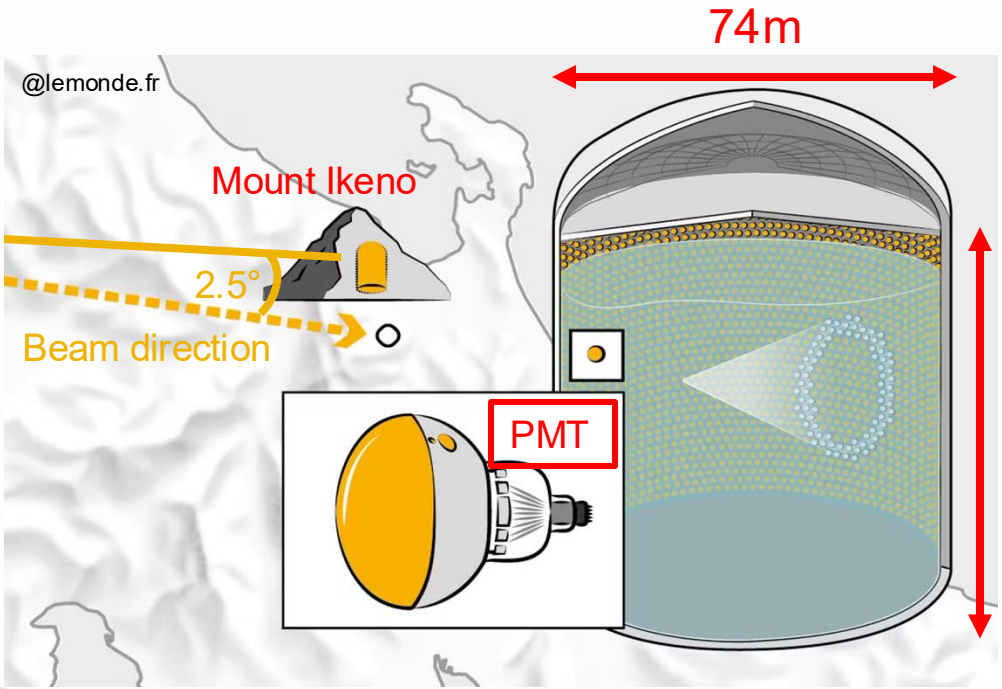
→ δ_{CP} - Mass order degeneracy !

Example: (δ_{CP} = 0, NMO) ⟷ (δ_{CP} = π, IMO)

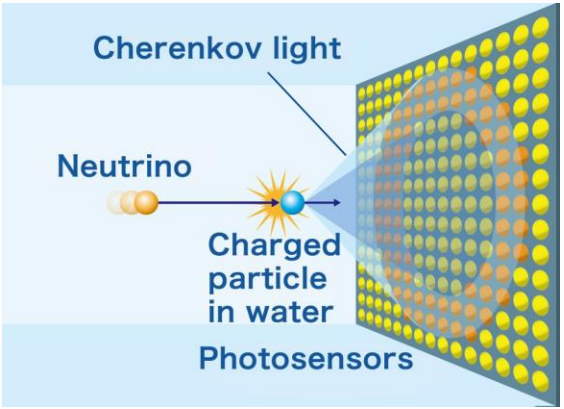
In 10 years of HK we can measure CPV @5sigma for a large range of values with the combined analysis

Technical design

HyperK design



Detection strategy



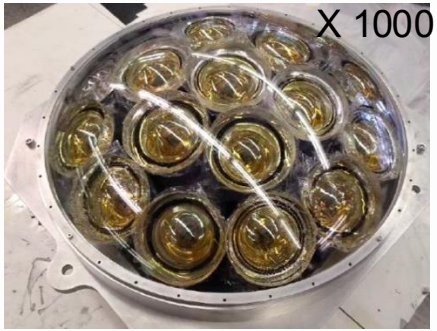
Technical design

- 250 k-tons of ultrapure water
- Inner detector
  → 20k PMTs + ~1k mPMT modules
  → 20% of photocoverage
- Outer detector (= veto)
  → 8k PMTs

HyperK design

Inner detector

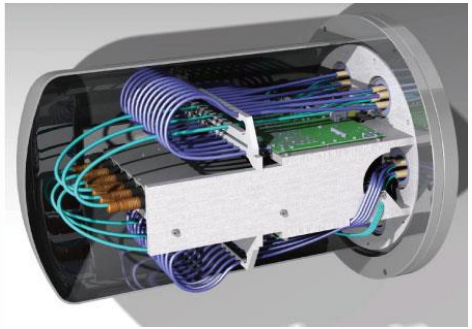
50cm Box & Line PMT



mPMT module:
19 single PMTs of 8cm

QE at peak wavelength	Charge resolution	Transit time spread (TTS)
~ 30 %	~ 30 %	2.6 ns

Underwater electronics

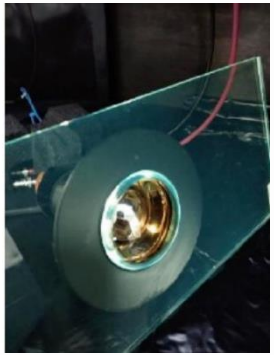


→ Waterproof
→ Antiseismic
→ High pressure resistant

Tested at CERN

Outer detector

X 8000



→ Veto system for cosmic rays

8cm high-sensitivity PMT (with wavelength shifting plates)

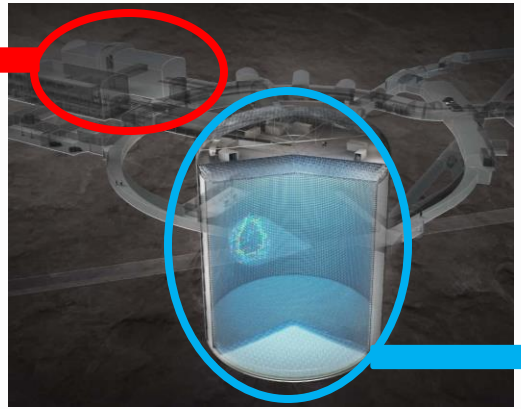
Project status

HyperK status: cavern excavation

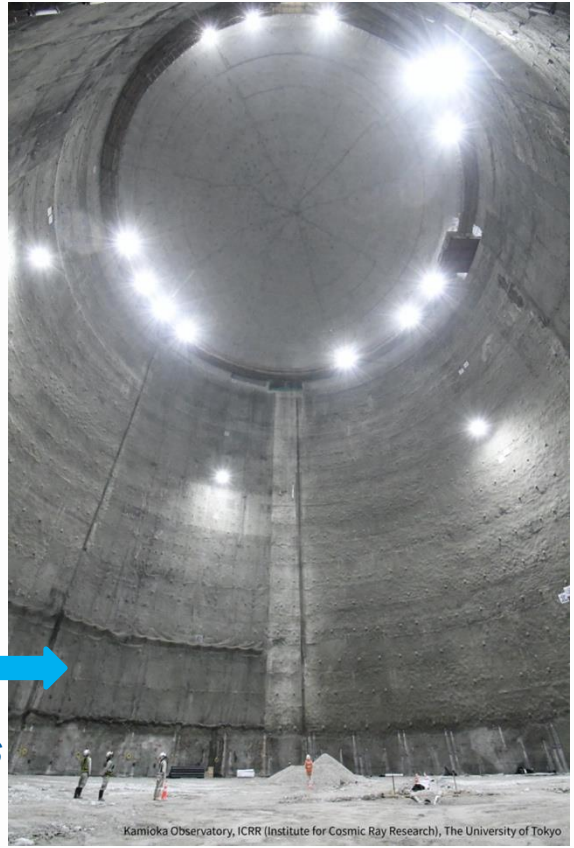
Cavern excavation finished in July 31st 2025 !

More details on: https://www.youtube.com/watch?v=Pw7tupVujlQ

Water purification system

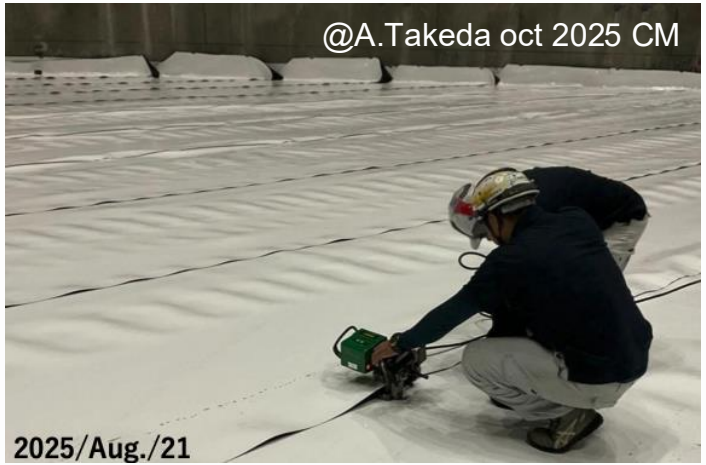


Dome and barrel sections



HyperK status: project schedule

@F.DiLodovico oct 2025 CM

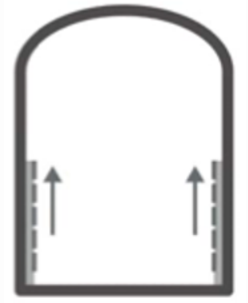


- Tank lining
- Water system
- Detector components

HyperK status: project schedule

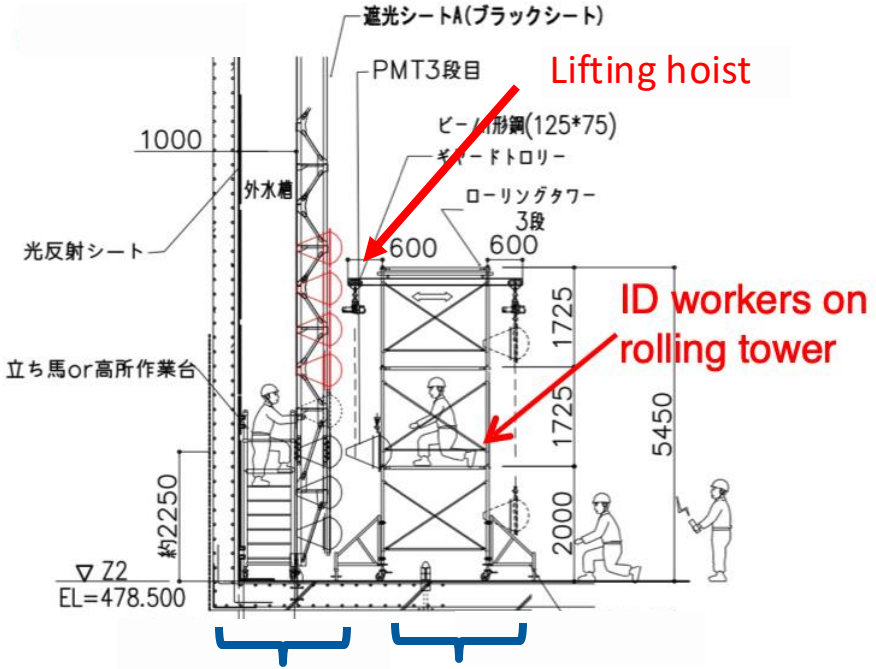
@F.DiLodovico oct 2025 CM

2025 → 08/2026 → 11/2027



- Tank lining
- Water system
- Detector components

- PMT installation
- Electronics
- Black sheet

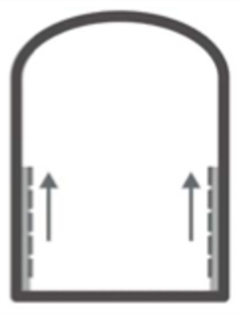


@H.Tanaka oct 2025 CM

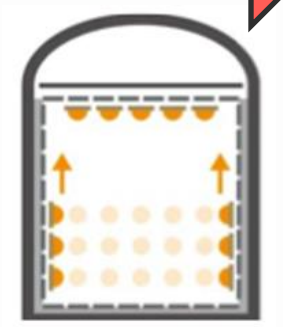
HyperK status: project schedule

@F.DiLodovico oct 2025 CM

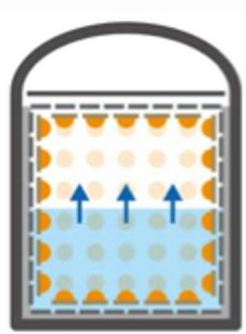
2025 → 08/2026 → 11/2027 → 11/2027 → 06/2028



- Tank lining
- Water system
- Detector components



- PMT installation
- Electronics
- Black sheet

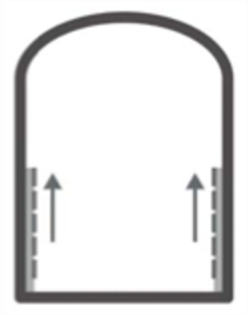


- Tank filling
- Detector commissioning

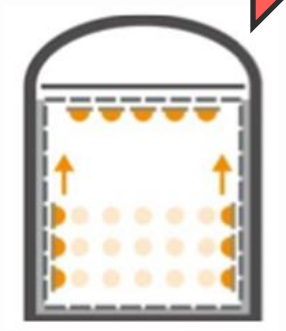
HyperK status: project schedule

@F.DiLodovico oct 2025 CM

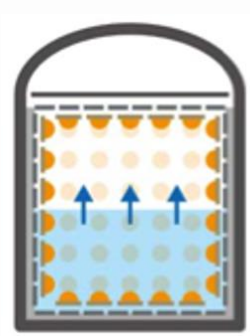
2025 → 08/2026 → 11/2027 → 11/2027 → 06/2028 → 06-2028



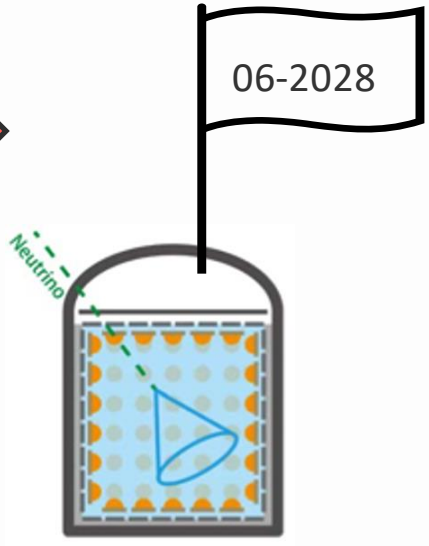
- Tank lining
- Water system
- Detector components



- PMT installation
- Electronics
- Black sheet



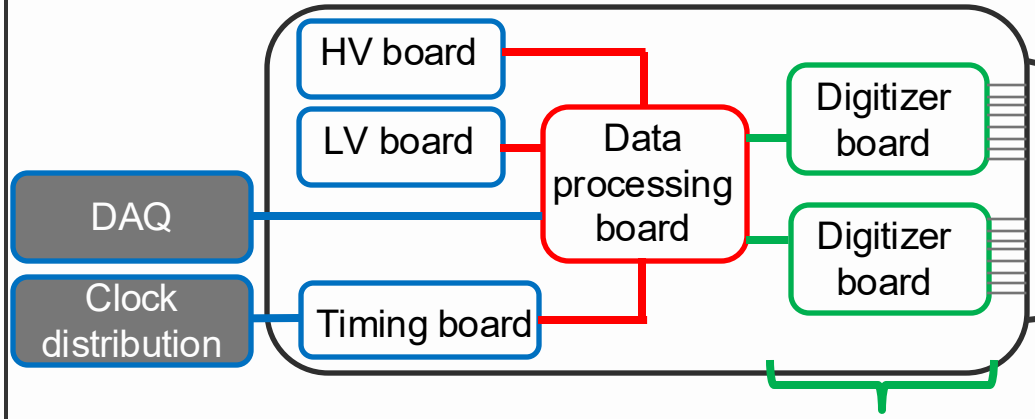
- Tank filling
- Detector commissioning

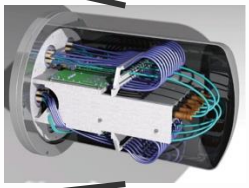


- Full scale operation!

French contributions

Calibration of the digitizer cards





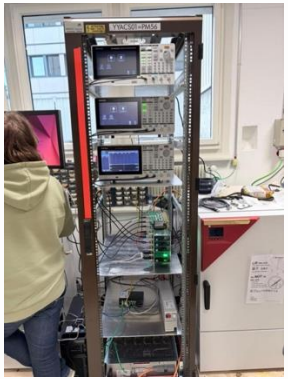
X 24

PMTs

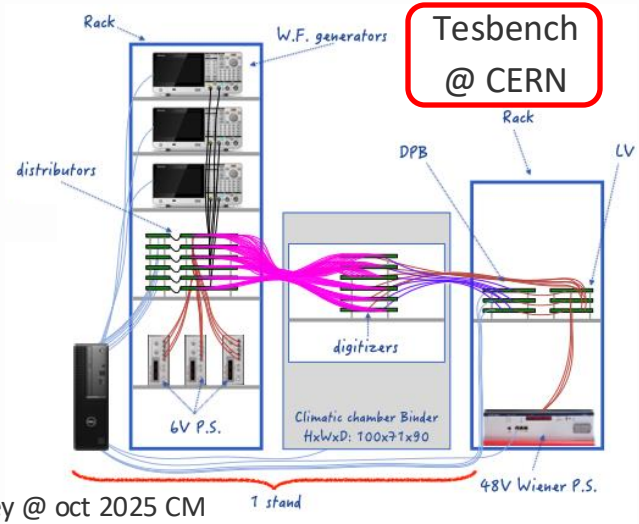
PMT signal → Digital signal

- Calibration of the digitizer boards :

✓ Hit threshold calibration
✓ Evaluation of the noise from the digitizers
✓ Temperature dependence

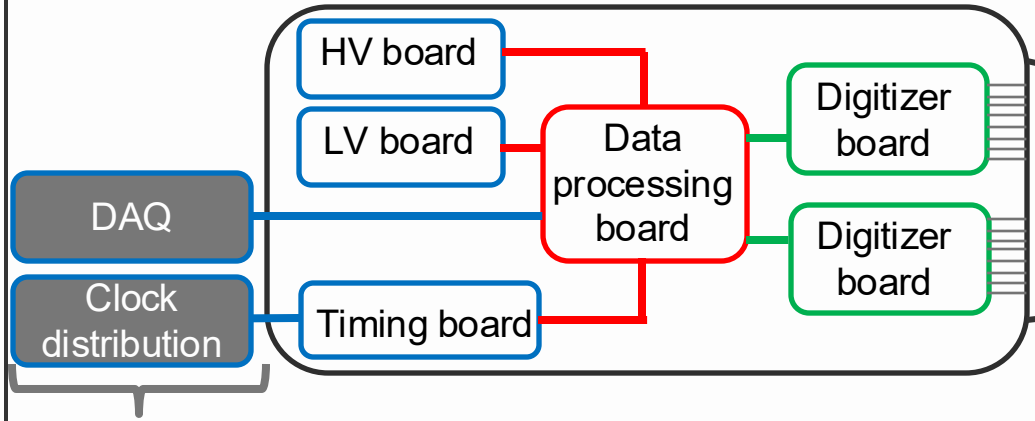


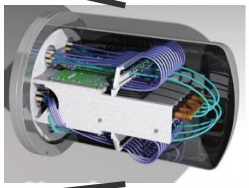
Tesbench @ CERN



T.Leplumey @ oct 2025 CM

Time distribution system





X 24

PMTs

Atomic clock (Cs)

Two stage distribution

Front-end electronics

→ ***Distribution module prototype***

- Contributions:
  - ✓ Design of the distributors
  - ✓ Production of the distributors
  - ✓ Synchronisation with UTC

  Paper on atomic clock correction methods: [NIMA 1075, 170358]
- HK requirements:
  - ✓ Internal synchronisation < 0.1 ns
  - ✓ External synchronisation < 100 ns

M.Guigue @ EPS HEP 2025

Reconstruction software (ongoing efforts)

- ***Low energy reconstruction (Solar, SuperNova ν):***

✓ Pure **Graph neutral network (GNN)** reconstruction

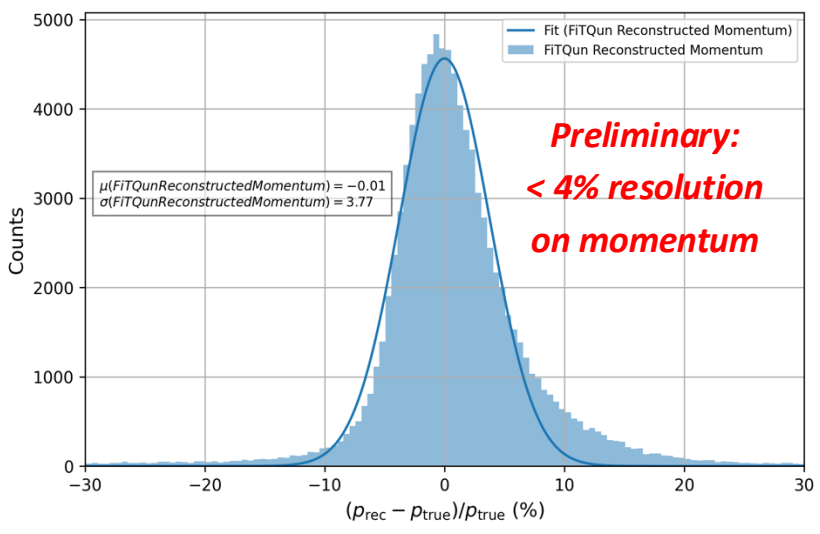
- ***High energy reconstruction (typical LBL ν):***

✓ Pure algorithmic reconstruction:
fiTQun algorithm = SK reconstruction

✓ Pure **Graph neutral network (GNN)** reconstruction
→ See 2024 IRN presentation by C.Quach:
https://indico.in2p3.fr/event/32480/contributions/138958/

✓ There are currently some efforts to build a **joint algorithmic-ML framework**

FiTQun momentum resolution for 10^5 electron particle guns with $p_{True} \in [20, 1500]$ MeV



Summary

- Vast physics program and opportunities
- Best sensitivity to proton decay
- Potential CPV discovery in only 3 years
- Design based on SuperK and well-known Cherenkov radiation detection method
- Cavern excavation completed in mid-2025

→ Full scale operation is planned from mid-2028

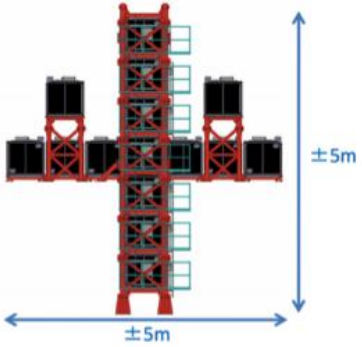
Cavern inauguration ceremony

- Many French contributions (CEA, LLR, LPNHE) in Hardware and Software

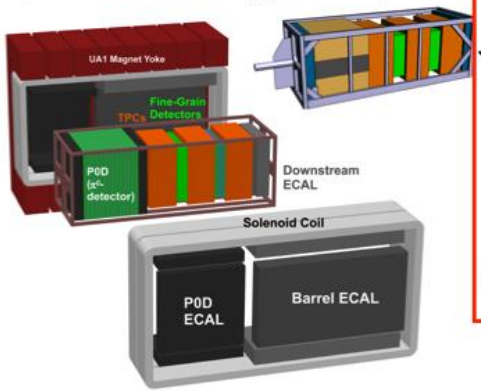
Backup

Near Detector Suite @M.Hartz WCTE meeting

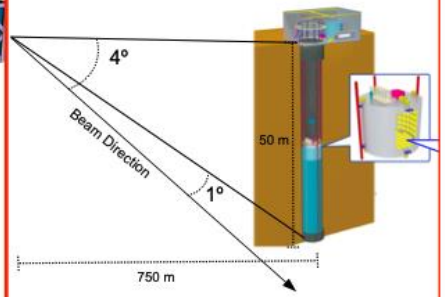
On-axis Detector (INGRID)



Off-axis Magnetized Tracker
(ND280→ND280 Upgrade→??)



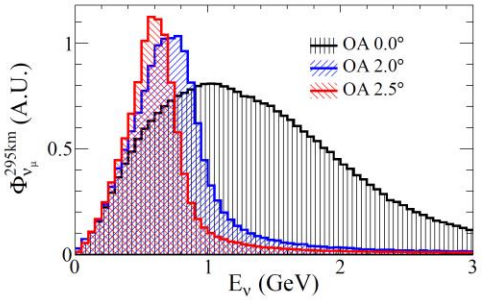
Off-axis spanning intermediate water Cherenkov detector (IWCD)



- On-axis detector: measure beam direction, monitor event rate
- Off-axis magnetized tracker: charge separation (measurement of wrong-sign background), study of recoil system
  - Expect upgrades of detector inherited from T2K will be necessary
- Off-axis spanning water Cherenkov detector: intrinsic backgrounds, electron (anti)neutrino cross-sections, neutrino energy vs. observables, H_2O target, neutron multiplicity measurement

10

→ Can probe relationship between neutrino energy and observed final states in water Cherenkov detector



→ Complementary approaches in IWCD and ND280. IWCD relies on flux model in linear combination method, but minimizes cross section model dependence. ND280 fits transverse variables to constrain cross section model.

Sensitivity studies (octant degeneracy)

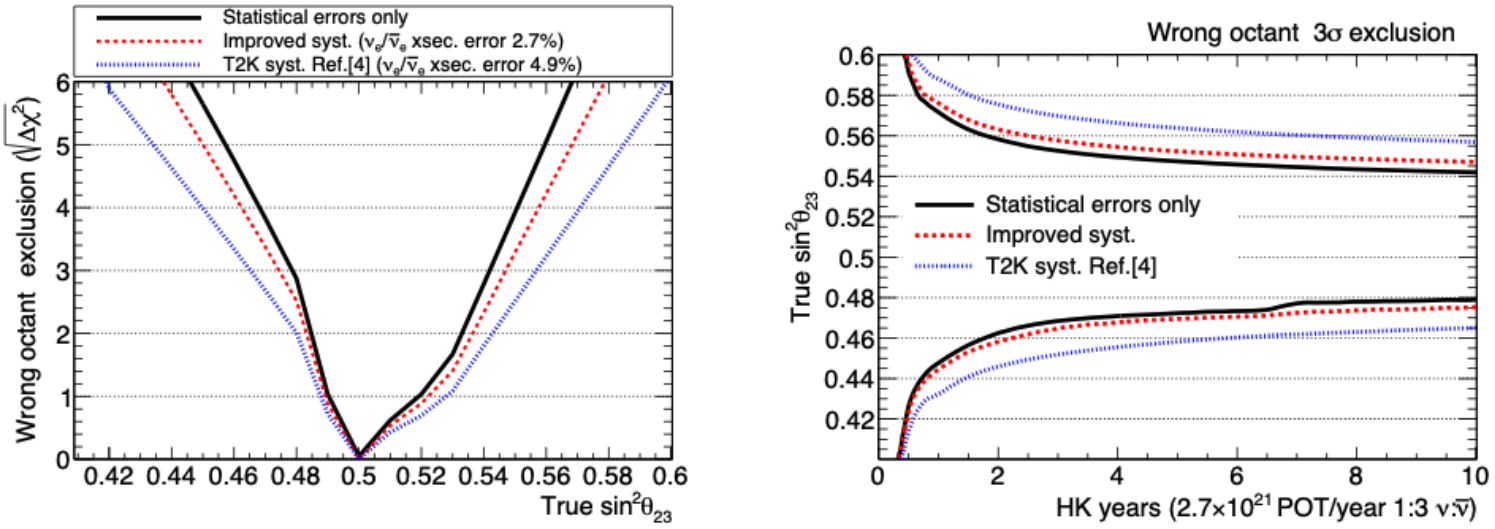


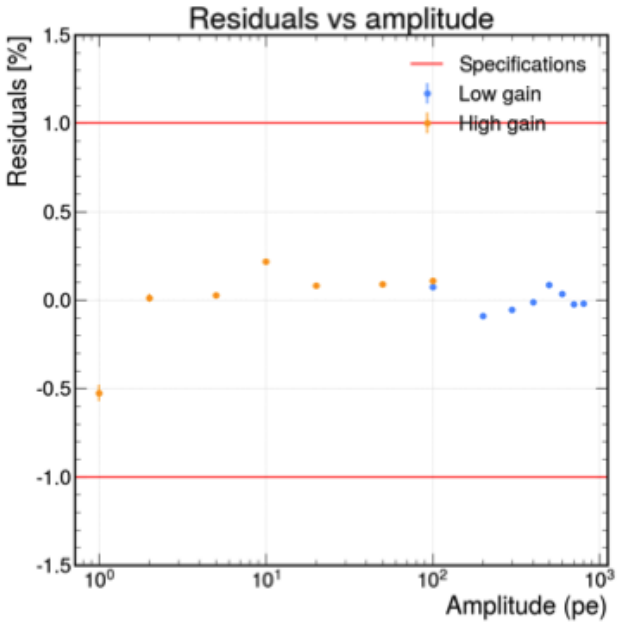
Fig. 6: Sensitivity to the wrong θ_{23} octant exclusion as a function of θ_{23} value after 10 years of data taking (left). θ_{23} region, as a function of data-taking time, for which 3σ exclusion of the wrong θ_{23} octant can be reached (right).

Linearity test (of the digitizer boards)

- Linear fit of the **high gain between 1pe and 100pe**
  - Limited range because of saturation effect
- Linear fit of the **low gain between 100pe and 800pe**
  - No saturation, but less precise

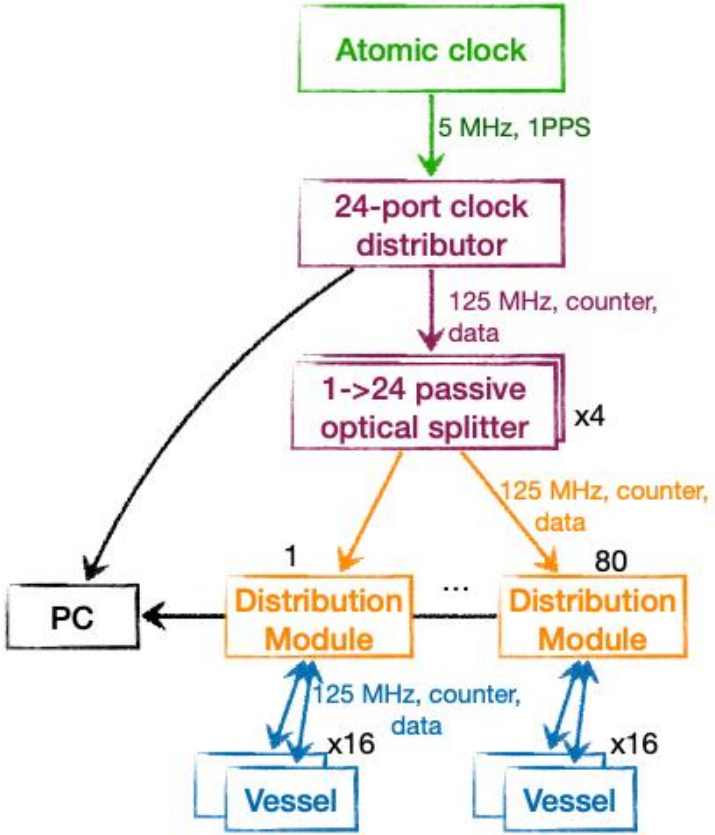
- The charge linearity has to be satisfied **within 1%**

$$\left|\frac{\text{gain}_{\text{p.s.}} - a \times \text{amp}}{a \times \text{amp}}\right| \leq 0.01$$



- High dependence on the temperature → has to be studied as well

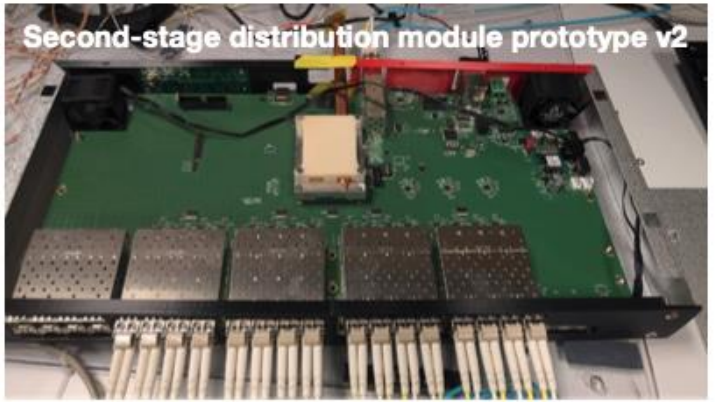
Clock distribution status



Two-stages distribution system
- Distribute/multiply atomic clock signals to 1000 vessels
- Propagate synchronous data to all vessels
- Based on Clock-in-Data-Recovery (CDR)

Full timing synchronisation test using function generator
- Realistic signal through digitiser, DPB
- < 300 ps resolution, consistent with TDC resolution

→ **Final production started — Ready by mid 2026**



UTC time synchronisation

- Apply online corrections to the atomic clock
- Polynomial fits for a given time window

Experimental setup to develop the correction techniques