



Hyper Kamiokande status and French contributions IRN neutrino 2025



Lorenzo Restrepo Orrantia (on behalf of the HyperK collaboration)

Physics program

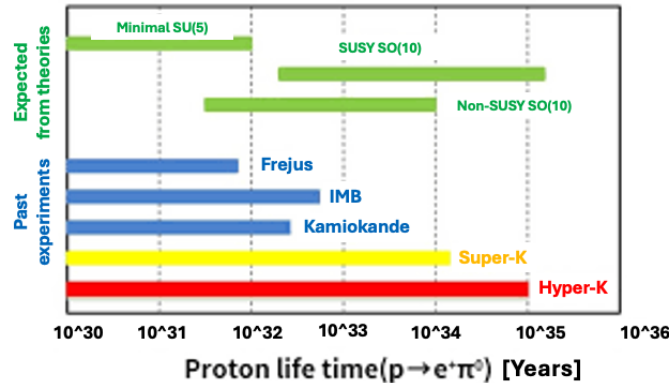
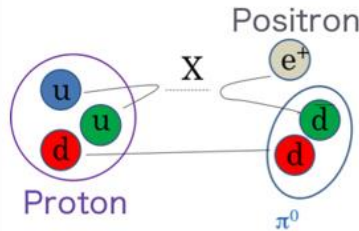
HyperK physics program

- 3rd generation **water Cherenkov** detector in Kamioka, Japan



Kamiokande (1983) $\xrightarrow{V \times 22.5}$ Super-Kamiokande (1996) $\xrightarrow{V \times 8}$ 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



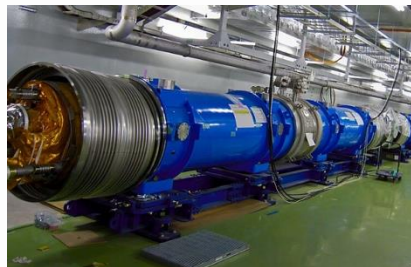
- ^8B spectrum
- Day-night asymmetry

Supernova neutrinos



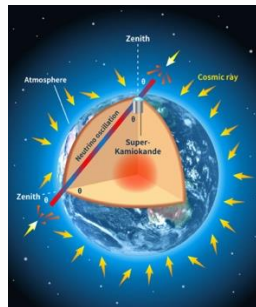
- Around 10^5 events expected for a galactic SN
- Model discrimination

Baseline neutrinos



- J-parc accelerator
- World-leading measurements of θ_{23} , Δm_{23}^2 , δ_{CP}

Atmospheric neutrinos

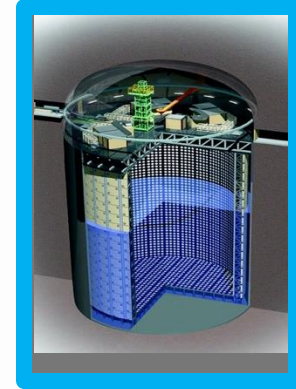
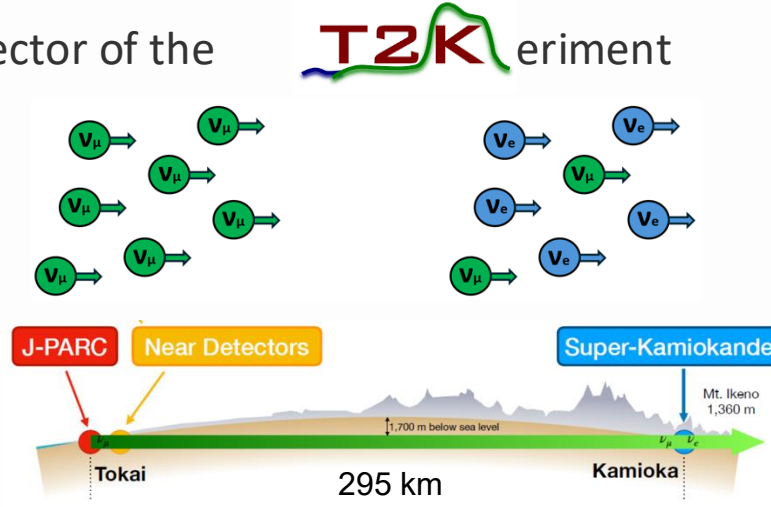


- Complement to the baseline program
- Mass hierarchy

About the Long Baseline program

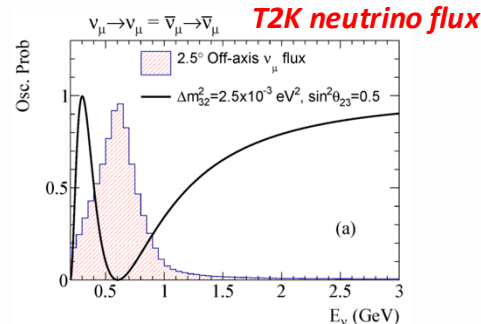
(See Pierre's talk!)

- HK will be the far detector of the **T2K** experiment



Near detectors:

- Ingrid
- ND280
- IWCD



Water Cherenkov detector
(2.5 degrees off axis):

- Now SuperK
- Soon HyperK

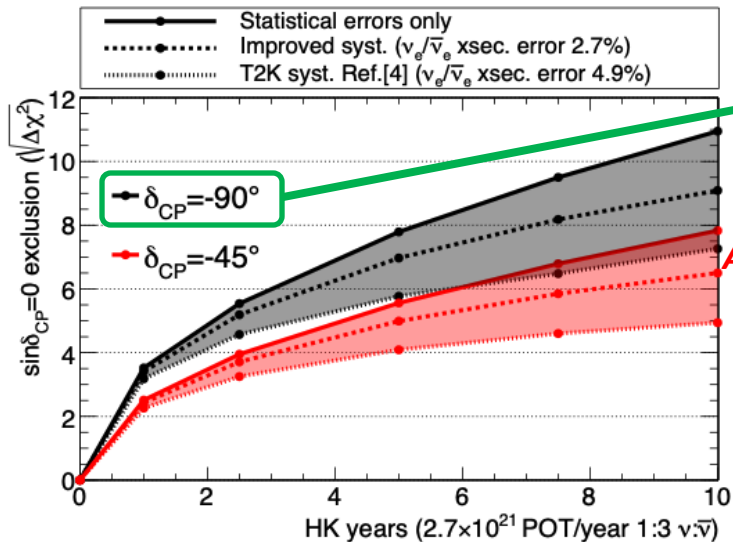
About the Long Baseline program

- **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 :

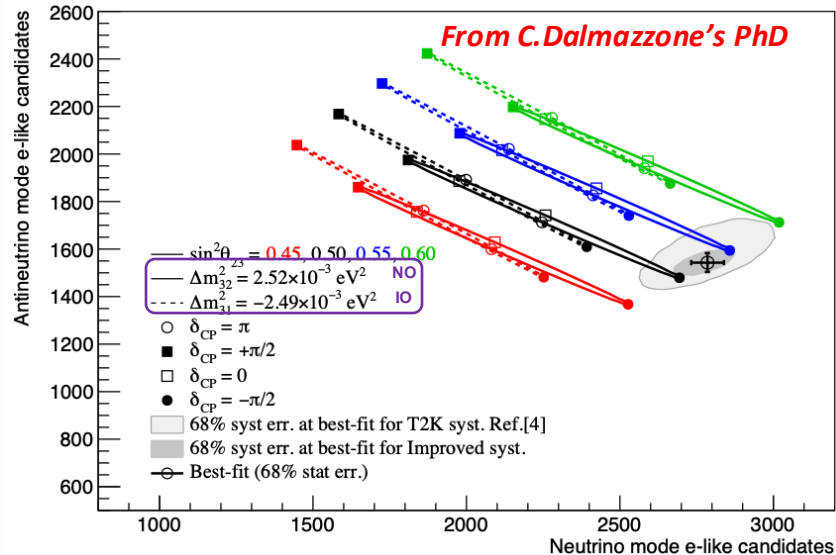
- ✓ θ_{23} (Octant degeneracy)
- ✓ Δm_{23}^2



“Sensitivity of the Hyper-Kamiokande experiment to neutrino oscillation parameters using acceleration neutrinos” [arXiv:2505.15019](https://arxiv.org/abs/2505.15019)

Combined analysis baseline + atmospheric

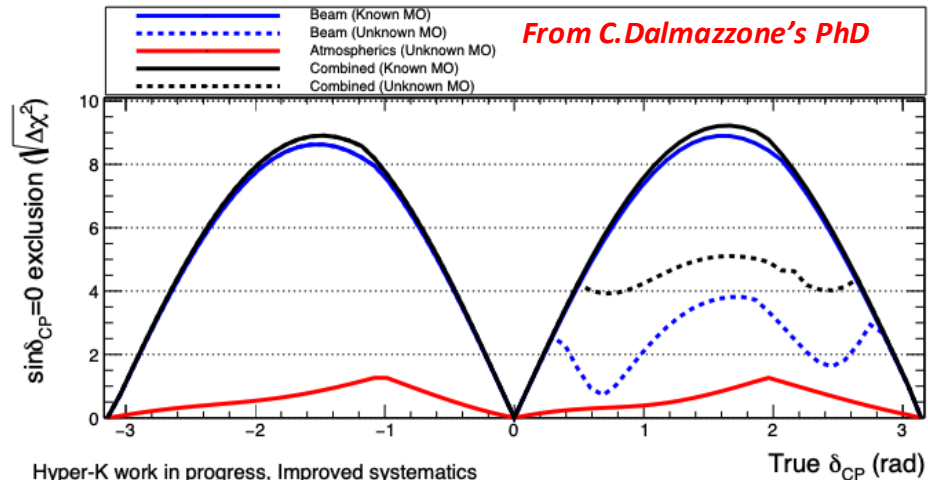
Expected $\bar{\nu}_e$ vs ν_e with 10 years of HK



→ δ_{CP} - Mass order **degeneracy** !

Example: ($\delta_{CP} = 0$, NMO) ← ($\delta_{CP} = \pi$, IMO)

Combined analysis with 10 years of HK



Hyper-K work in progress, Improved systematics

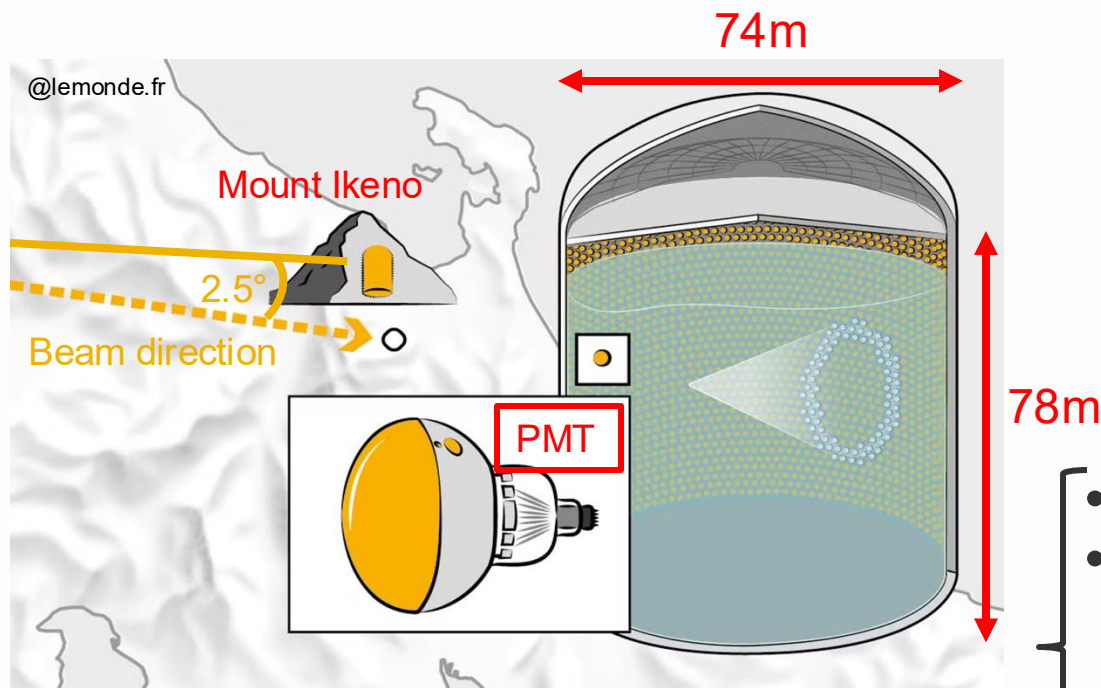
True Normal Ordering, 10 years (2.7×10^{22} POT 1:3 $\nu:\bar{\nu}$)

$\sin^2 \theta_{13} = 0.0218 \pm 0.0007$, $\sin^2 \theta_{23} = 0.528$, $\Delta m_{32}^2 = 2.509 \times 10^{-3} \text{ eV}^2/c^4$

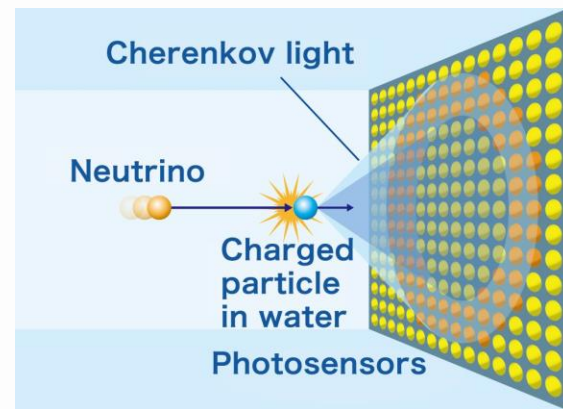
In 10 years of HK we can measure CPV @5sigma for a large range of values with the combined analysis

Technical design

HyperK design



Detection strategy



Technical design

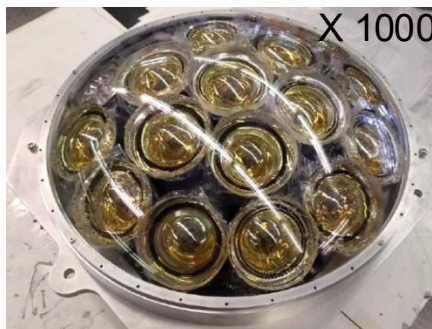
- 250 k-tons of ultrapure water
- Inner detector
 - 20k PMTs + 1k mPMT modules
 - 20% of photocoverage
- Outer detector (= veto)
 - 8k PMTs

HyperK design

Inner detector



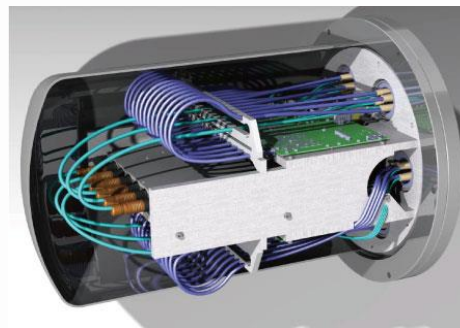
50cm Box & Line PMT



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

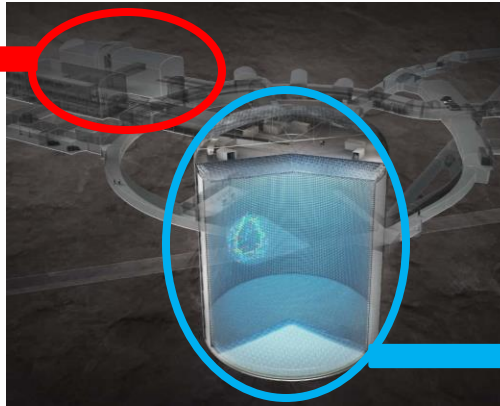
HyperK status: cavern excavation

Cavern excavation finished in July 31st 2025 !

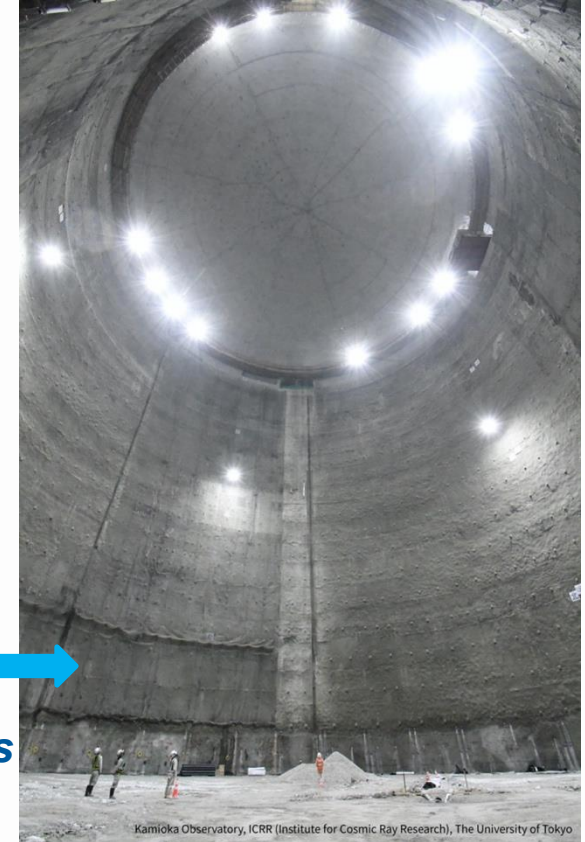
More details on: <https://www.youtube.com/watch?v=Pw7tupVujlQ>



Water purification system



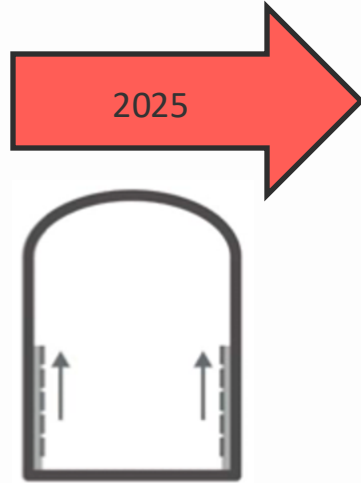
Dome and barrel sections



Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), The University of Tokyo

HyperK status: project schedule

@F.DiLodovico oct 2025 CM

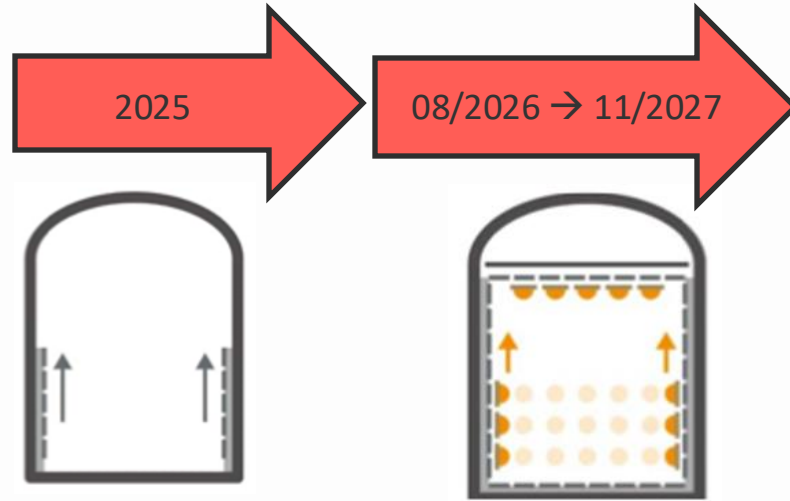


- Tank lining
- Water system
- Detector components



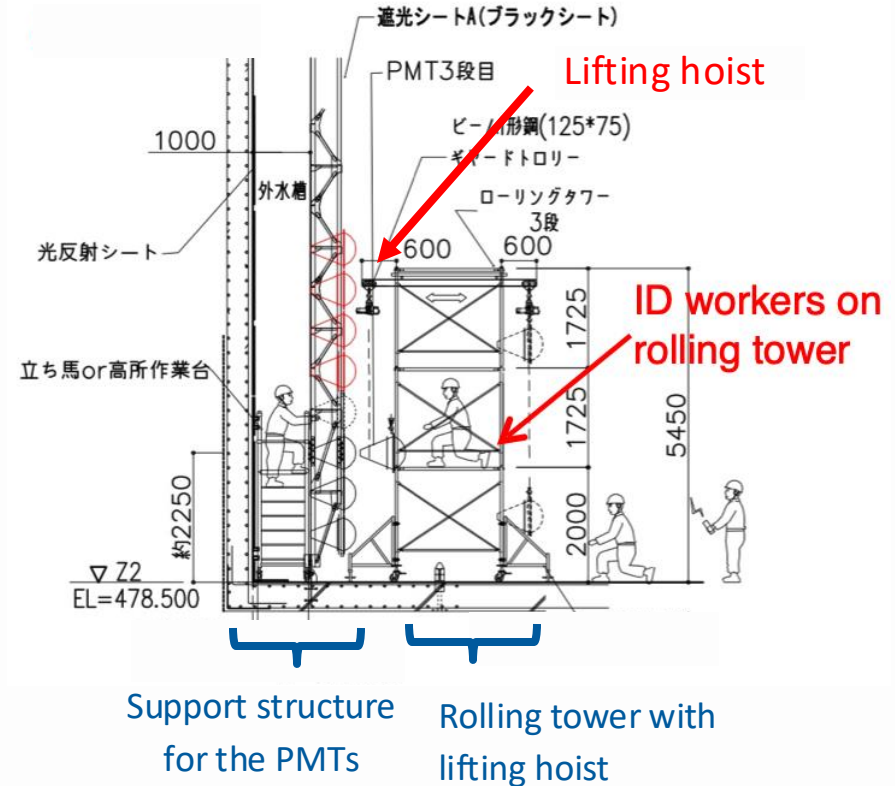
HyperK status: project schedule

@F.DiLodovico oct 2025 CM



- Tank lining
- Water system
- Detector components

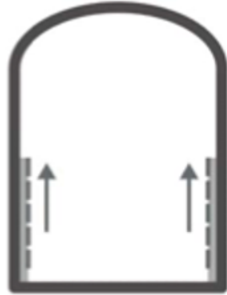
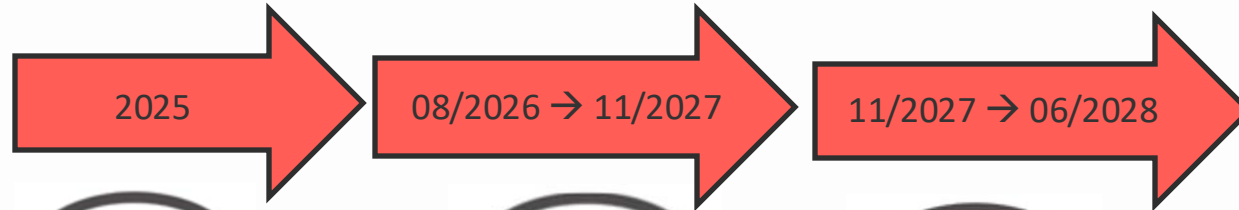
- PMT installation
- Electronics
- Black sheet



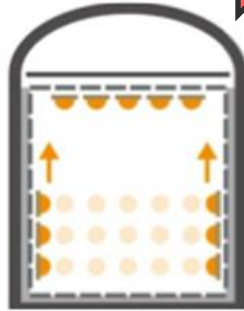
@H.Tanaka oct 2025 CM

HyperK status: project schedule

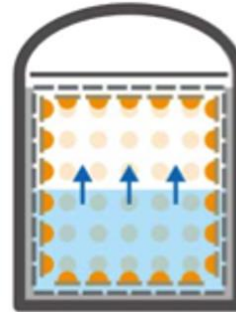
@F.DiLodovico oct 2025 CM



- Tank lining
- Water system
- Detector components



- PMT installation
- Electronics
- Black sheet

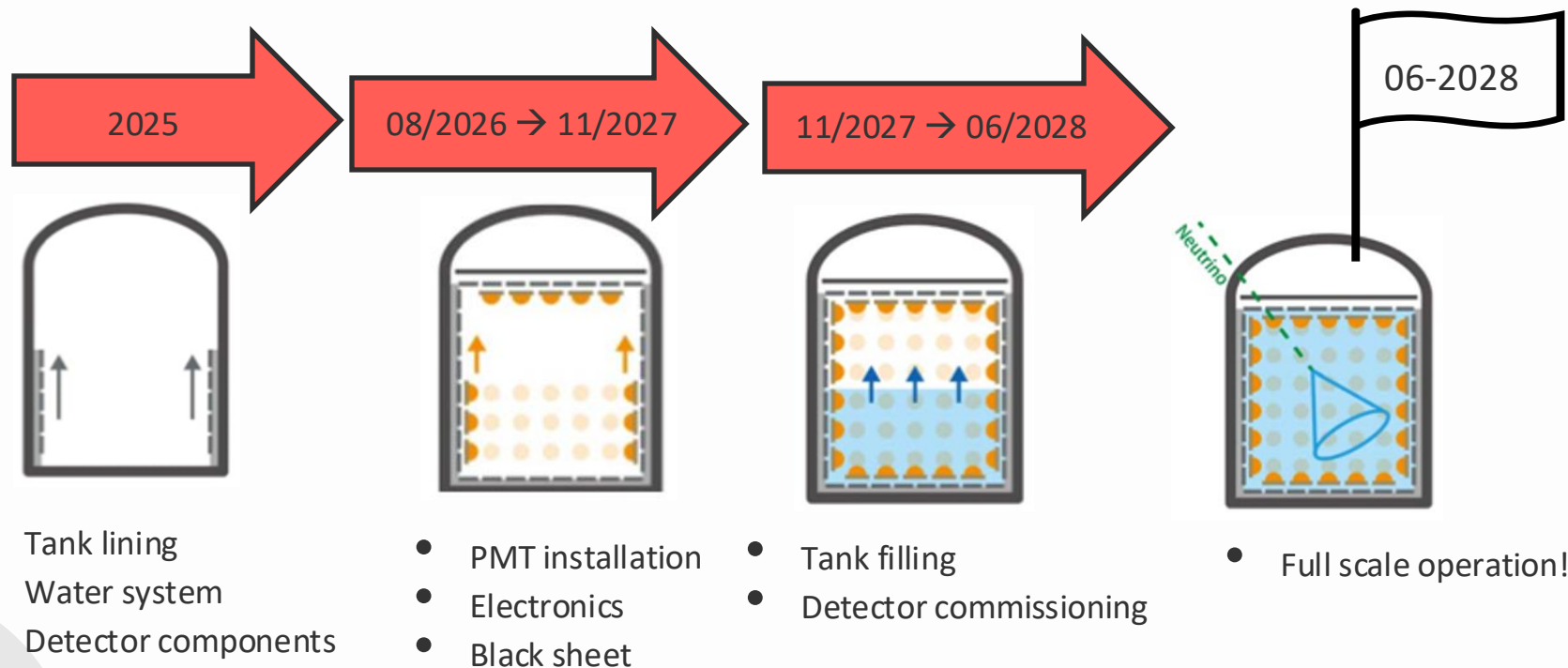


- Tank filling
- Detector commissioning



HyperK status: project schedule

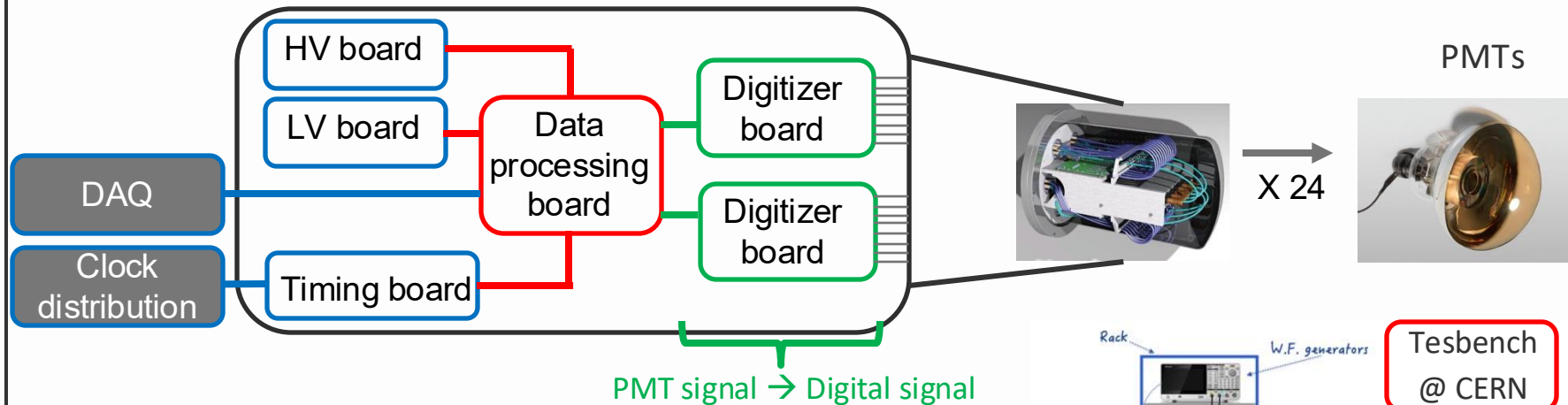
@F.DiLodovico oct 2025 CM



French contributions

Calibration of the digitizer cards

10

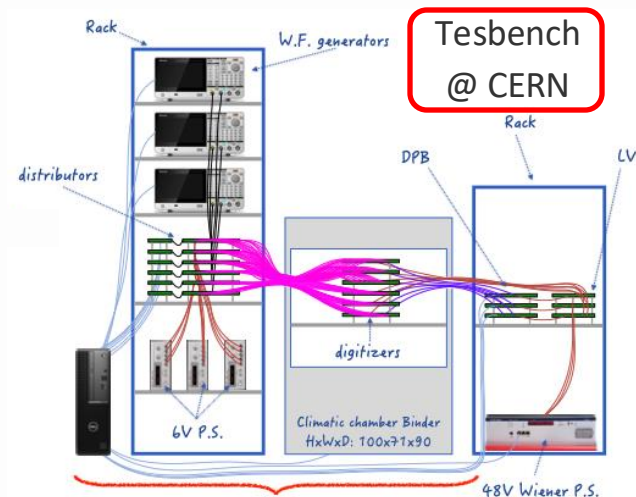


- Calibration of the **digitizer boards** :

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

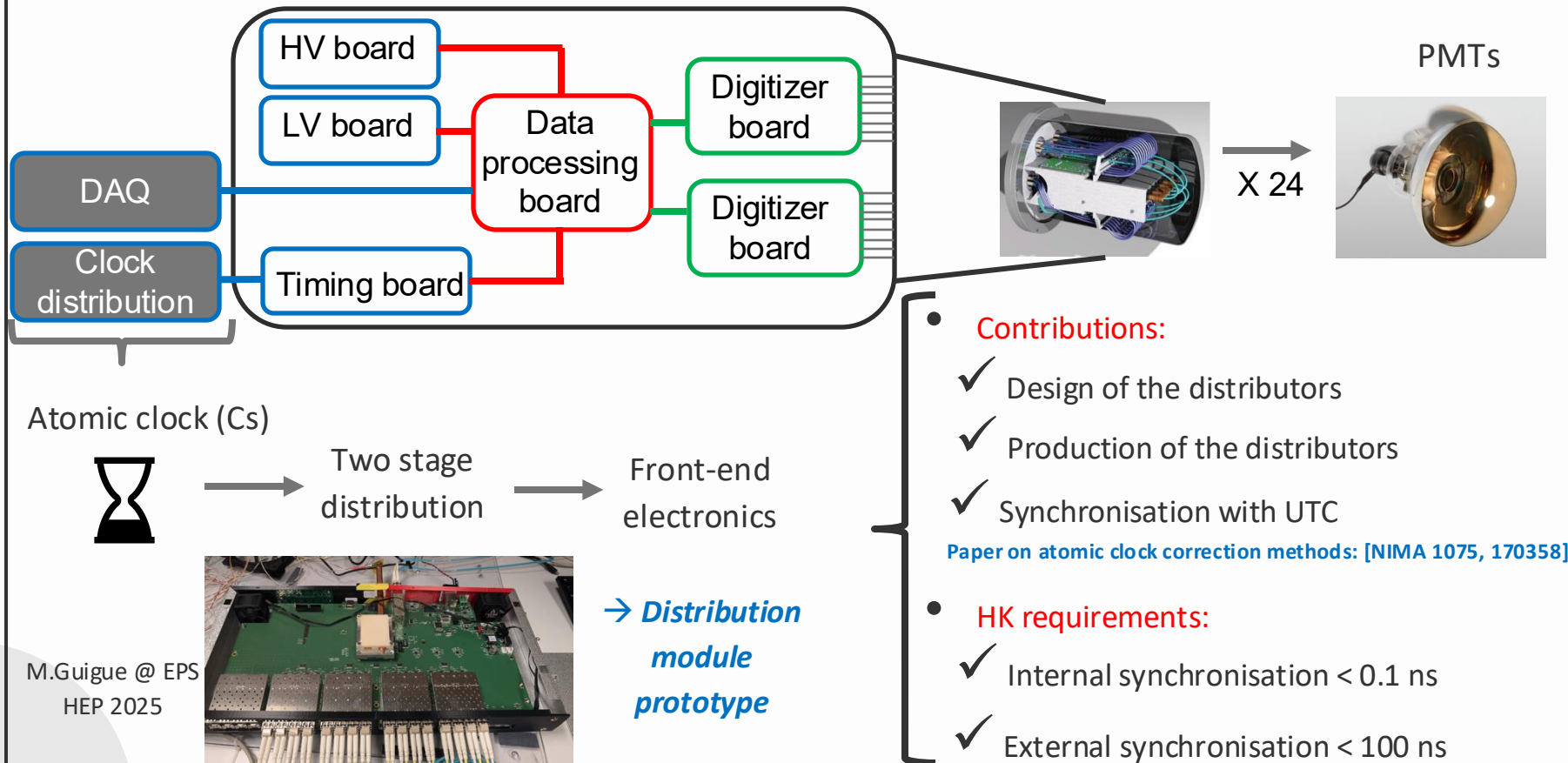


T.Leplumey @ oct 2025 CM



Time distribution system

11



Reconstruction software (ongoing efforts)

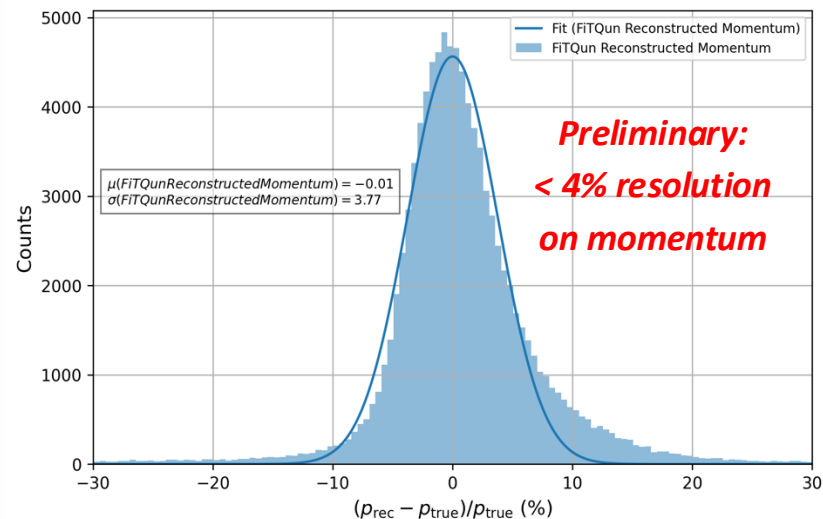
- Low energy reconstruction (Solar, SuperNOva ν):

- ✓ 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
- Potential **CPV discovery** in only **3 years**
- Design based SuperK and on well-known Cherenkov radiation detection method
- **Cavern excavation completed** in mid-2025
→ Full scale operation is planned from mid-2028
- Many French contributions (CEA, LLR, LPNHE) in **Hardware** and **Software**

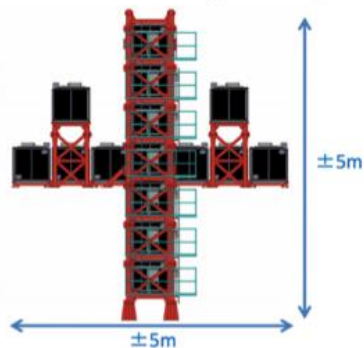
Cavern inauguration ceremony



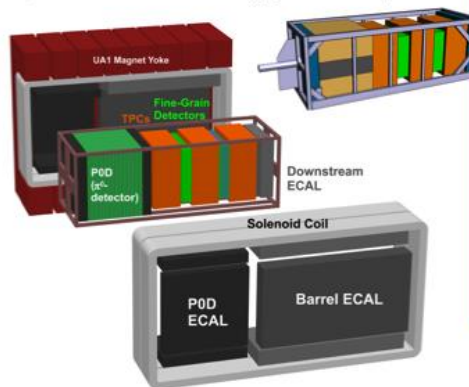
Backup

- Near Detector Suite @M.Hartz WCTE meeting

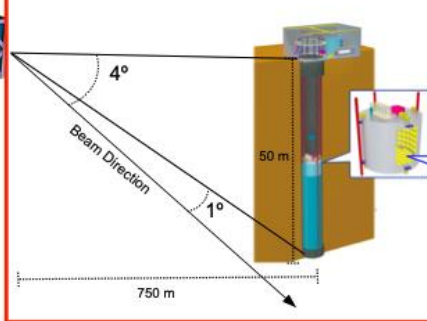
On-axis Detector (INGRID)



Off-axis Magnetized Tracker
(ND280 $\rightarrow$ ND280 Upgrade $\rightarrow$??)

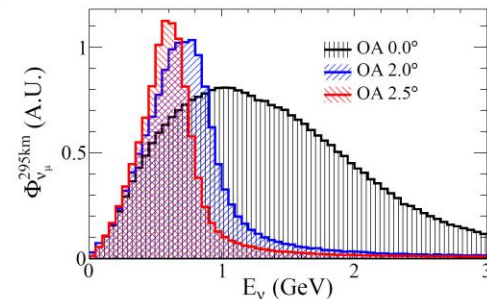


Off-axis spanning intermediate water Cherenkov detector (IWCD)



$\rightarrow$ Can probe relationship between neutrino energy and observed final states in water Cherenkov detector

- 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



$\rightarrow$ 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)

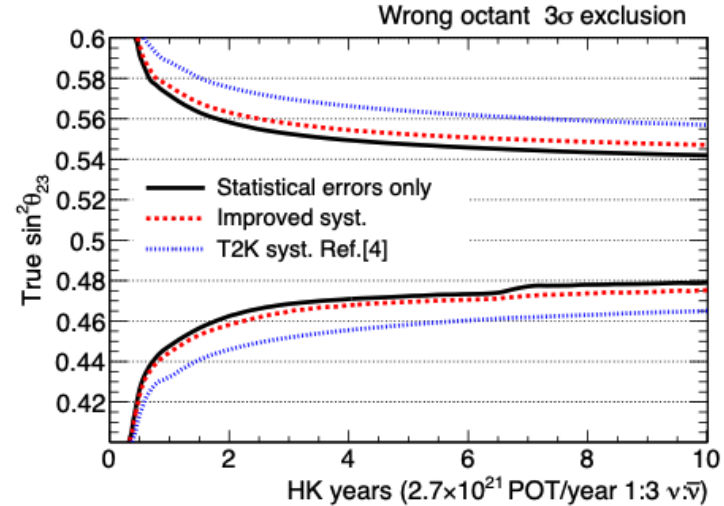
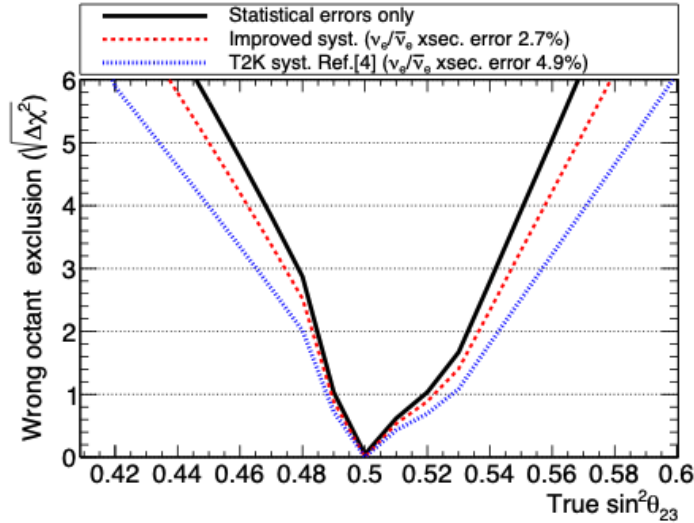
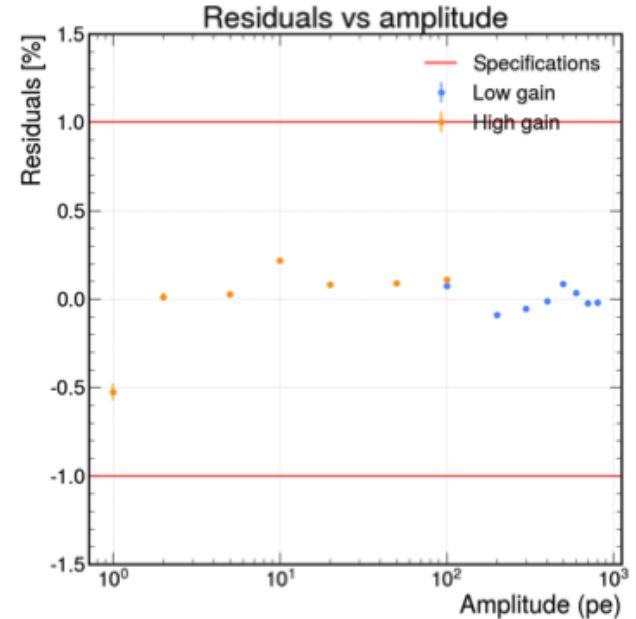


Fig. 6: Sensitivity to the wrong θ_{23} octant exclusion as a function of θ_{23} value after 10 years of data taking (left). θ_{23} region, as a function of data-taking time, for which 3σ exclusion of the wrong θ_{23} octant can be reached (right).

Linearity test (of the digitizer boards)

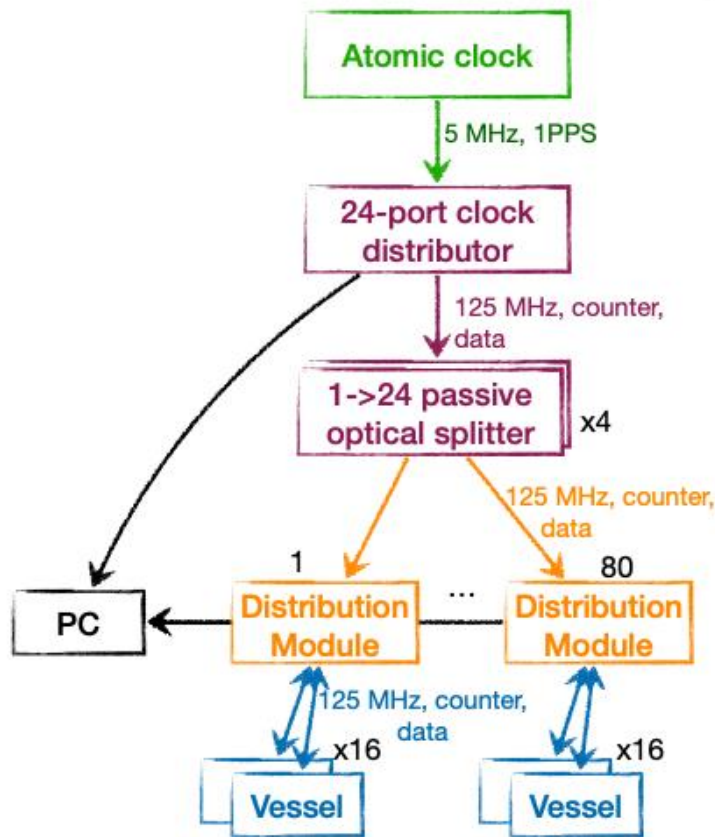
- Linear fit of the **high gain between 1pe and 100pe**
 - Limited range because of saturation effect
- Linear fit of the **low gain between 100pe and 800pe**
 - No saturation, but less precise
- The charge linearity has to be satisfied **within 1%**

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



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

Clock distribution status



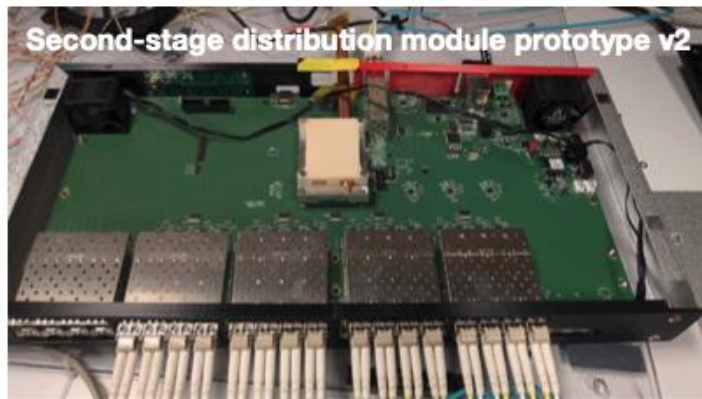
Two-stages distribution system

- 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**

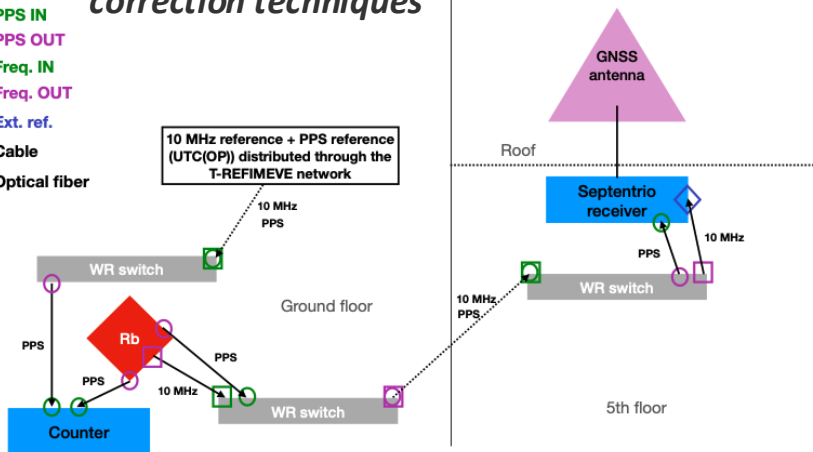


UTC time synchronisation

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

Experimental setup to develop the correction techniques

- PPS IN
- PPS OUT
- Freq. IN
- Freq. OUT
- ◇ Ext. ref.
- Cable
- Optical fiber



Online correction

