The Long-Baseline Neutrino program in Japan

Davide Sgalaberna (ETH Zurich)

CHIPP Roadmap workshop

January 18th 2023

Swiss involvement

- Scientific goals: precision measurement of neutrino oscillations

  ⇒ Measurement of the leptonic CP violating phase

  ⇒ Neutrino Mass Ordering determination

- Experiments: T2K & Hyper-K in Japan

CHIPP Board members	Institute	FTE
Prof. Federico Sanches	UniGe	1
Prof. Davide Sgalaberna	ETHZ	1
Prof. André Rubbia	ETHZ	0.25
Total		**2.25**

Senior Scientists	Institute	FTE
Dr. Stefania Bordoni	UniGe	1
Dr. Alessandro Bravar	UniGe	0.20
Dr. Umut Kose	ETHZ	1
Total		**2.20**

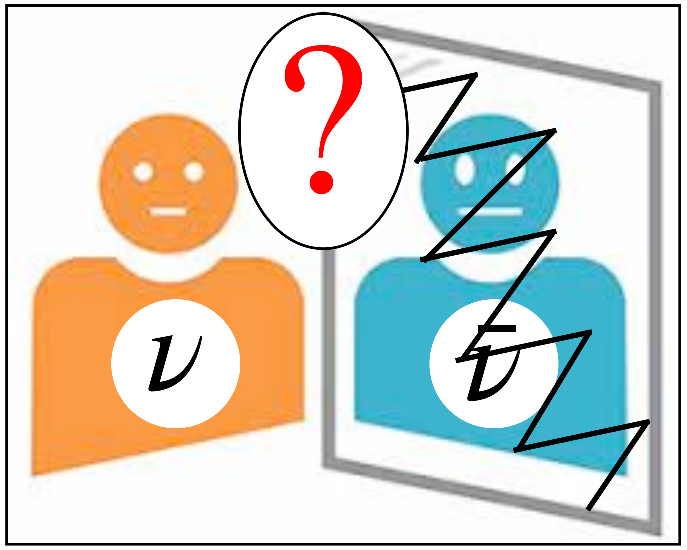
ETHZ and UniGe collaborates very closely on hardware and data analysis on both the T2K and Hyper-K oscillation experiments

Current status in Japan: the T2K latest results

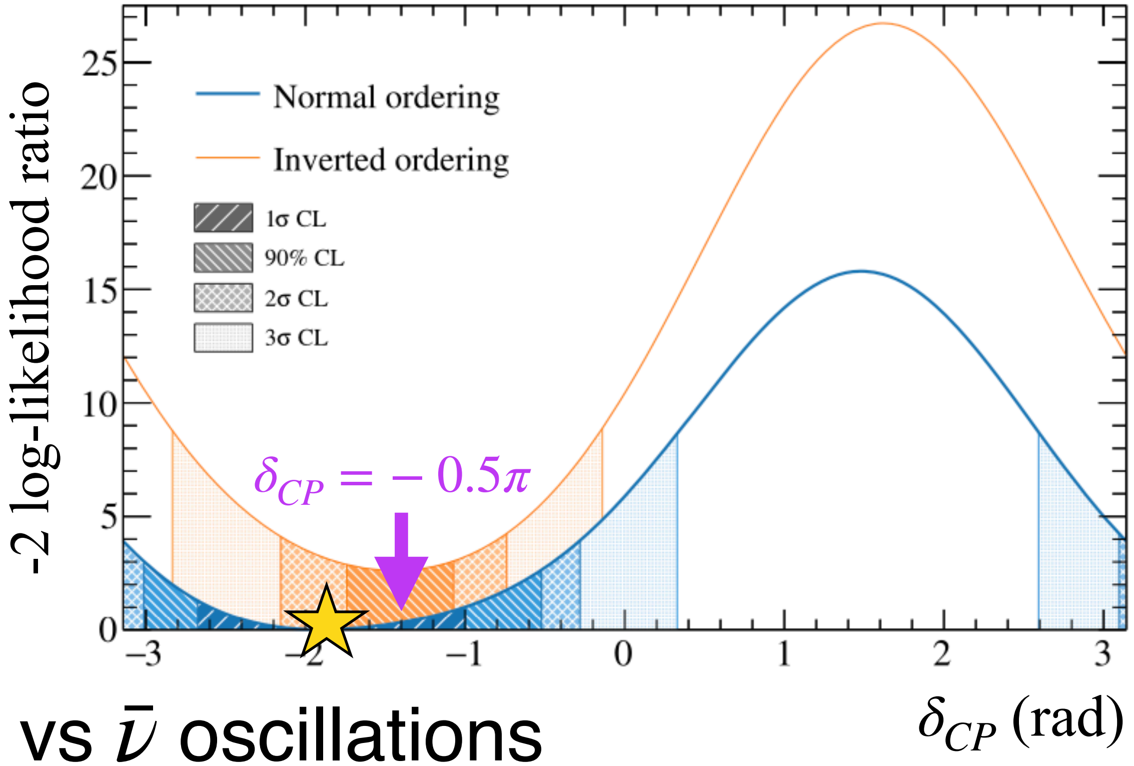
- Long-baseline accelerator ν oscillation experiments measure the oscillation probabilities $\nu_\mu \to \nu_x$ and $\nu_\mu \to \nu_e$

✓Prof. Sanchez has just completed the 2nd mandate as Spokeperson

Leptonic CP violation from asymmetry in $\nu_\mu \to \nu_e$ vs $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations



T2K Collaboration, Eur. Phys. J. C (2023) 83:782



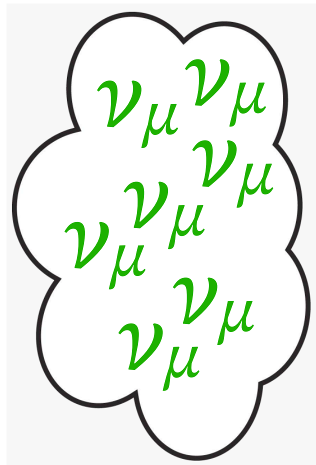
- T2K data observe a maximal difference ν vs $\bar{\nu}$ oscillations
  ⇒ maximal CP violation and normal mass ordering are favoured
- Also finalised joint analyses with other experiment collaborations:

  ✓T2K + Super-K atmospheric ν and T2K + NOνA

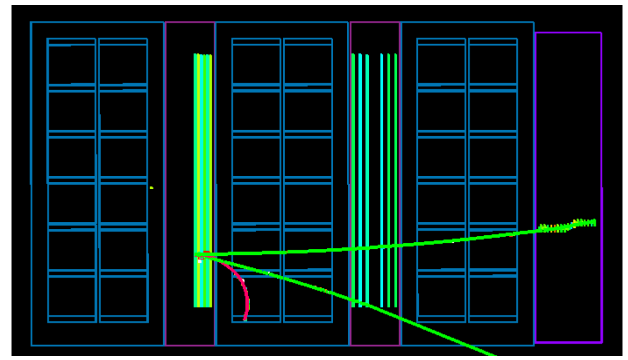
The search for CP violation is still dominated by statistical uncertainties

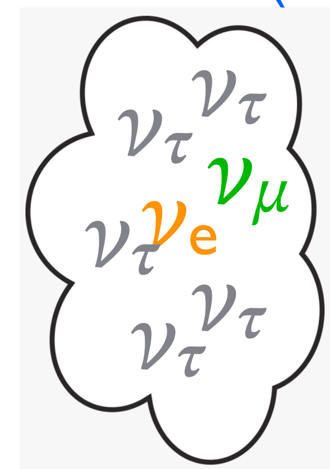
Requirements for δ_{CP} measurement

J-PARC Accelerator and ν beamline

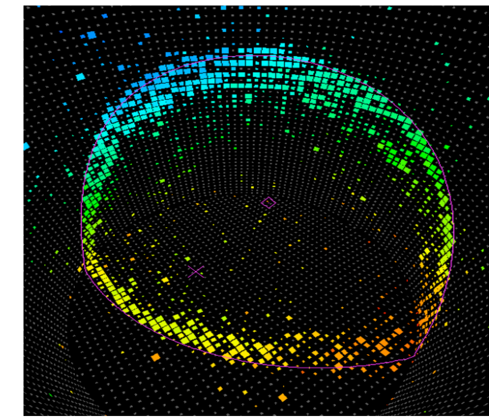


Near Detector (ND280)

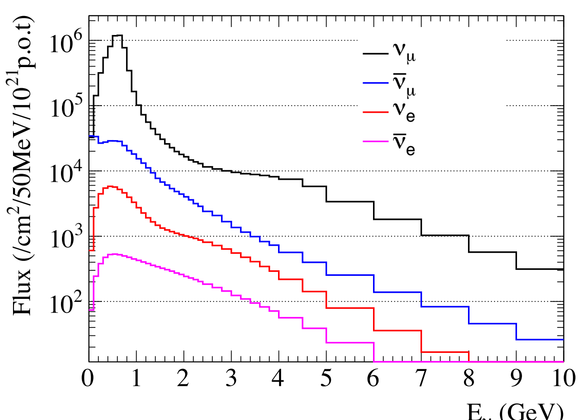




Far Detector (Super-K / Hyper-K)

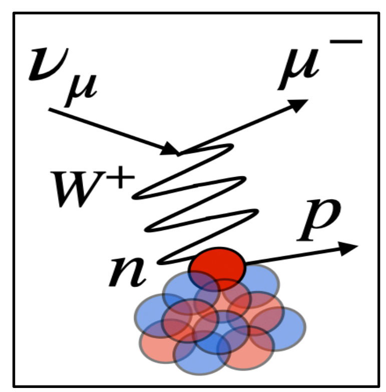


0 km — 280 m - - - 295 km →



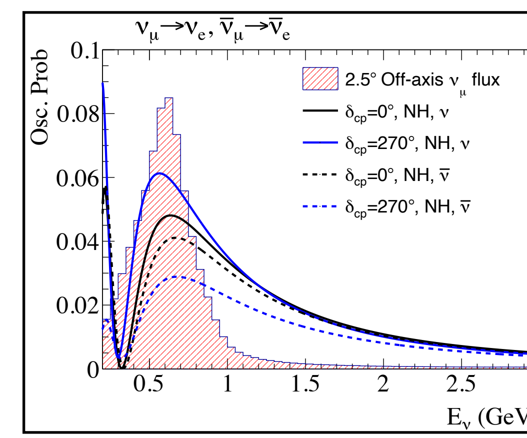
Flux

$\otimes$



Cross section

$\otimes$

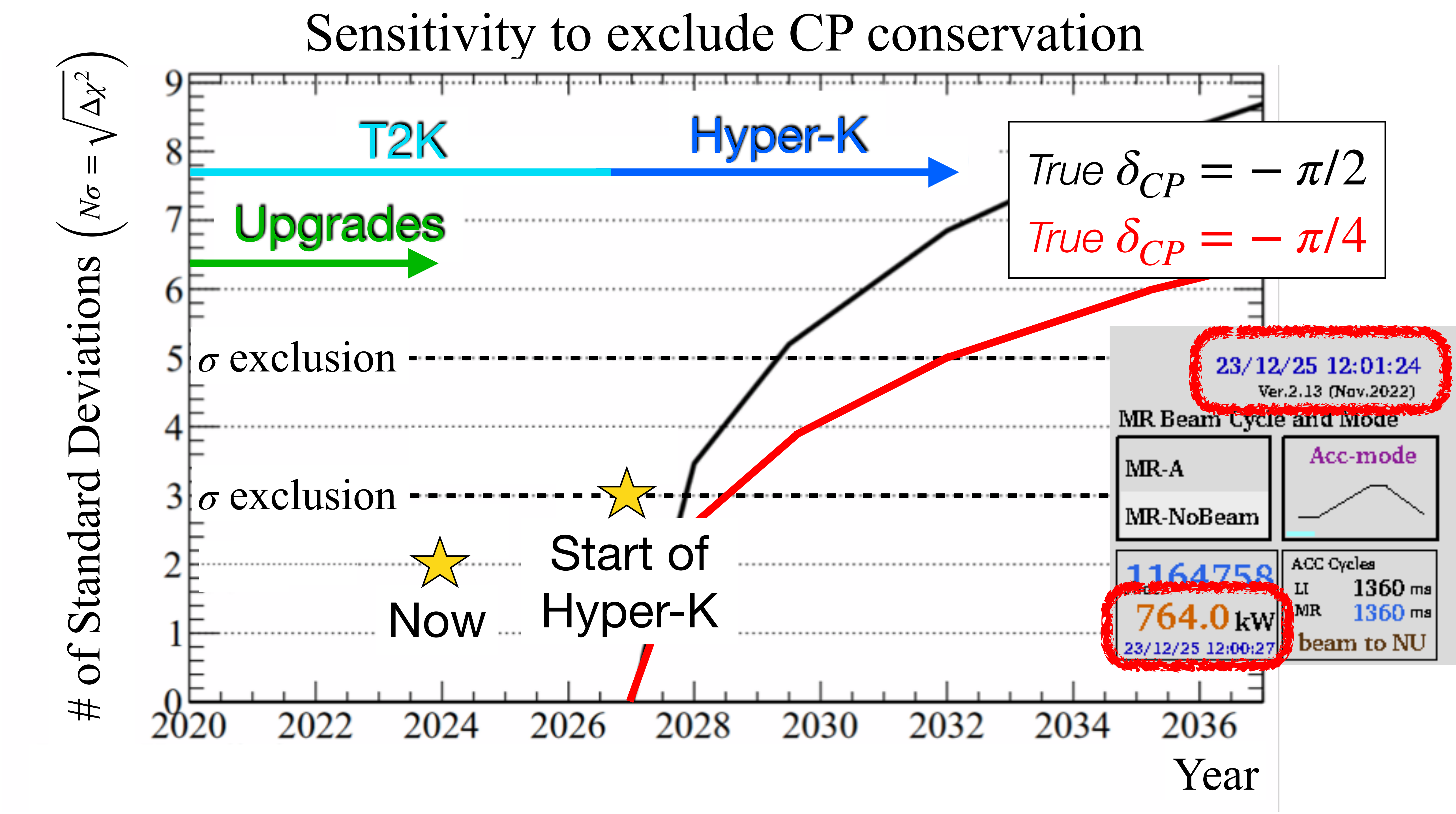


Oscillations

Reduce statistical uncertainties
- Neutrino beam intensity >1MW
- Bigger Far Detector

Reduce systematic uncertainties
- Upgrade of the Near Detector

Roadmap towards the measurement of δ_{CP}



Neutrino beam has been restarted in Nov. 23 after the long-shutdown

The beam intensity will reach 1MW in 2025 and 1.3MW in 2028

The upgrade of ND280

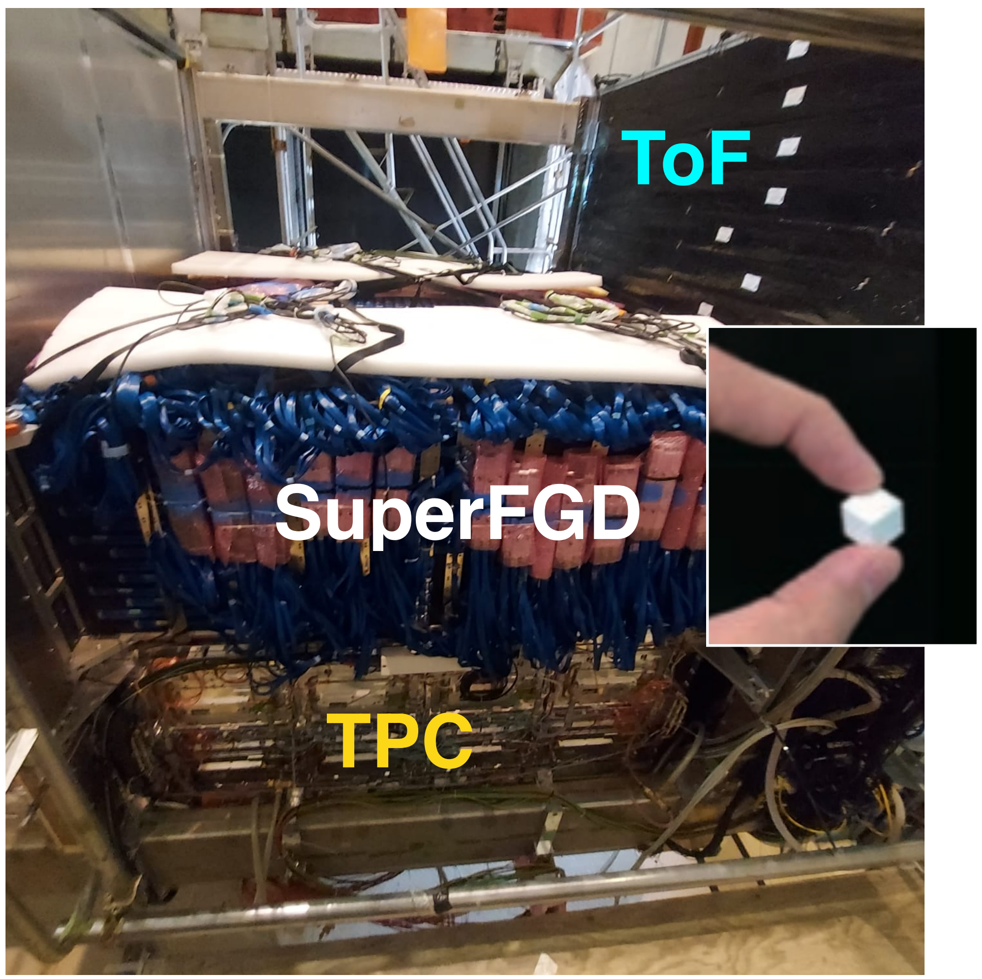
FLARE 21-22 funded

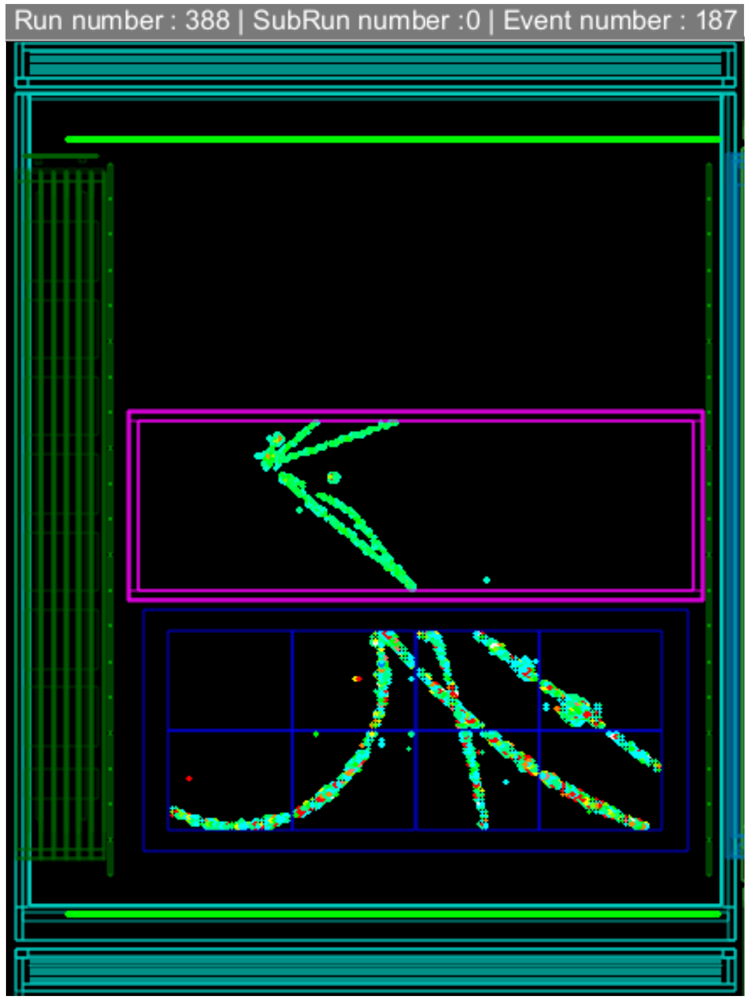
Major contributions to SuperFGD mechanics/electronics and ToF detectors

- Successfully collected neutrino beam data in Fall ’23. More data in Feb.’24

✓Prof. Sgalaberna convener of SuperFGD detector working group

✓Dr. Bordoni convener of ToF detector working group





Developing physics analyses to reduce systematics related to ν-nucleus interactions

✓Prof. Sgalaberna convener of T2K ND280 Physics working group

Participation in T2K until 2027 (contribution to common funds)

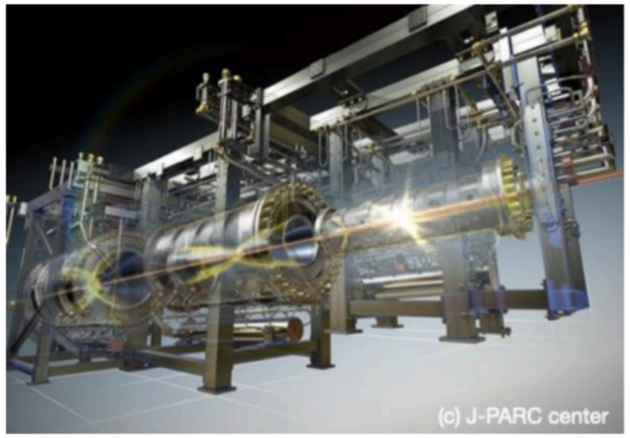
FLARE 25-26 to request

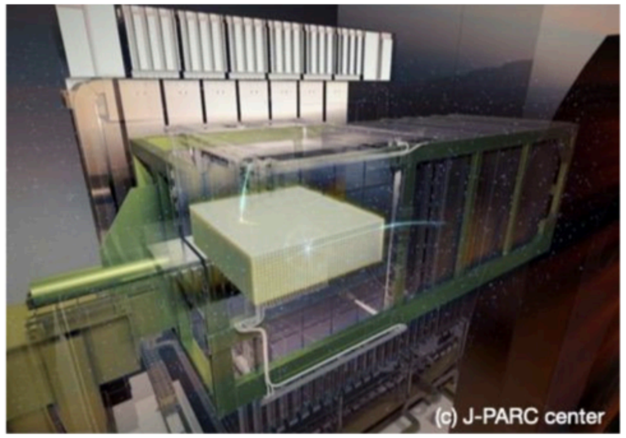
T2K experiment enters a new phase with significantly improved sensitivity for its world leading neutrino oscillation research

16 January 2024 - High Energy Accelerator Research Organization (KEK)

The T2K Collaboration has started data taking using the enhanced neutrino beam and new neutrino near-detectors from December 2023. The KEK/J-PARC center has upgraded the main ring accelerator and the neutrino beamline to increase the beam power. T2K has also upgraded its neutrino production instruments. The stable operation of neutrino beam has been successfully achieved at a record high beam intensity (about 710 kW), an increase of about 40% compared to before the upgrade. Furthermore, on December 25th, the continuous operation of neutrino beam has been successfully achieved at 760kW, which is greater than the initial design beam power. The pulsed electromagnet (electromagnetic horn) system, the heart of the neutrino generator, was also upgraded. The current applied to the electromagnetic horn has been increased from 250 kA to 320 kA. This allowed us to increase the neutrino intensity by about 10%. In addition, T2K installed new neutrino detectors that can measure neutrino interactions with even higher precision than before. The newly installed detectors consist of SuperFGD, which detects tracks around a neutrino interaction point inside the detector, High-Angle TPC, which measures momentum of particles emitted over a wide range of angles, and Time-of-Flight, which can detect incoming or outgoing particles and identify particles. Neutrino event candidates were successfully observed during a technical run of the new detectors after the start of beam operation. In 2020, the T2K gave the first hints that the symmetry between matter and antimatter could be violated in neutrino oscillations. With these enhancements, T2K will continue to lead the world in advancing the understanding of neutrino properties and unraveling the mystery of the absence of antimatter in the universe.

More detailed information on this announcement can be found from the KEK webpage:
https://www.kek.jp/en/press-en/202401171405/





DATE ISSUED:

January 16th, 2024

SOURCE:

High Energy Accelerator Research Organization (KEK)

CONTENT:

Press Release

CONTACT:

High Energy Accelerator Research Organization (KEK)
E-mail: press@kek.jp

Check out the new press release from T2K !

INTERACTIONS.ORG
PARTICLE PHYSICS NEWS AND RESOURCES

Hyper-K Far Detector (FD)

Same experimental configuration as T2K

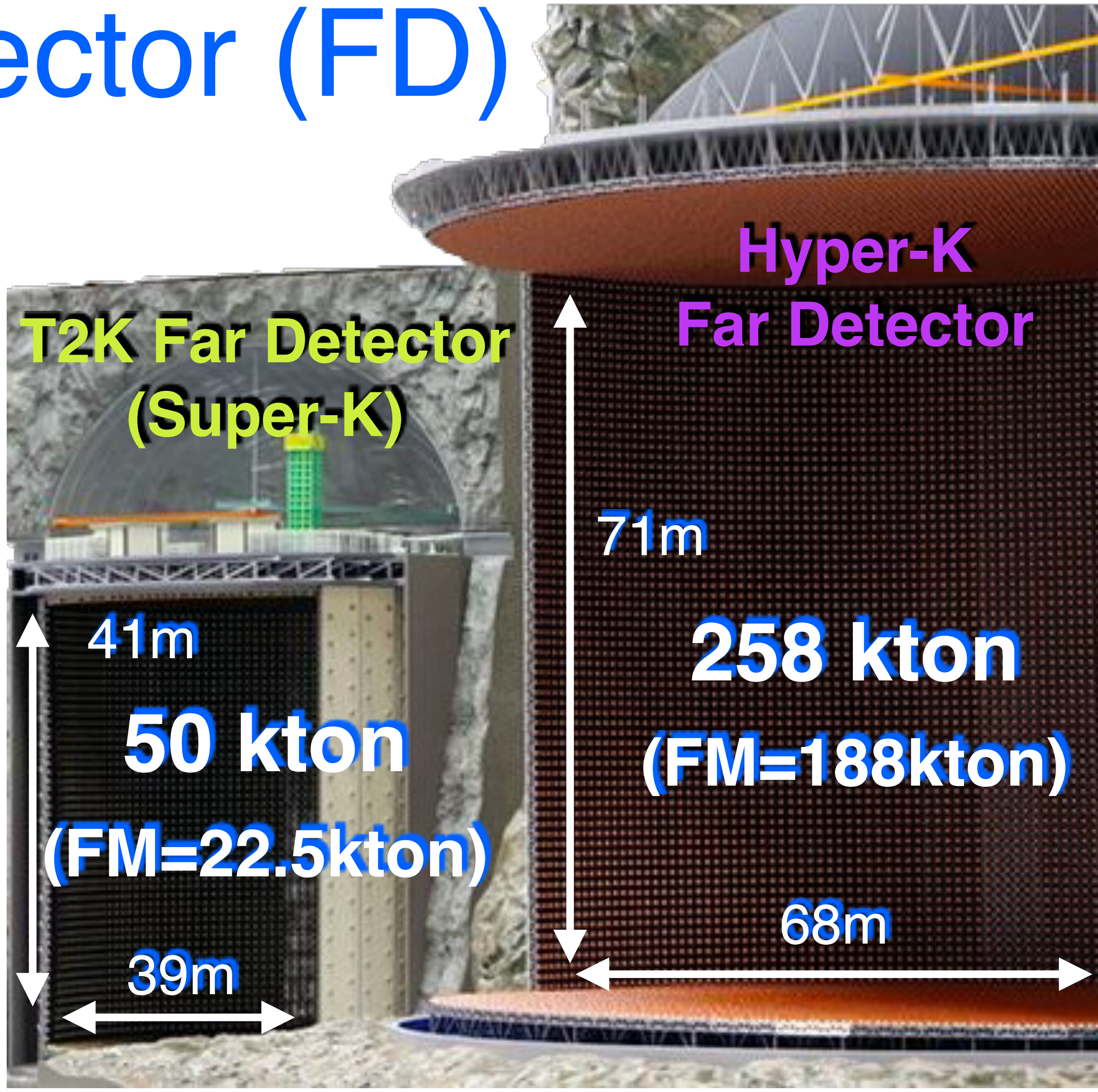
✓Inherit the neutrino beam and ND280

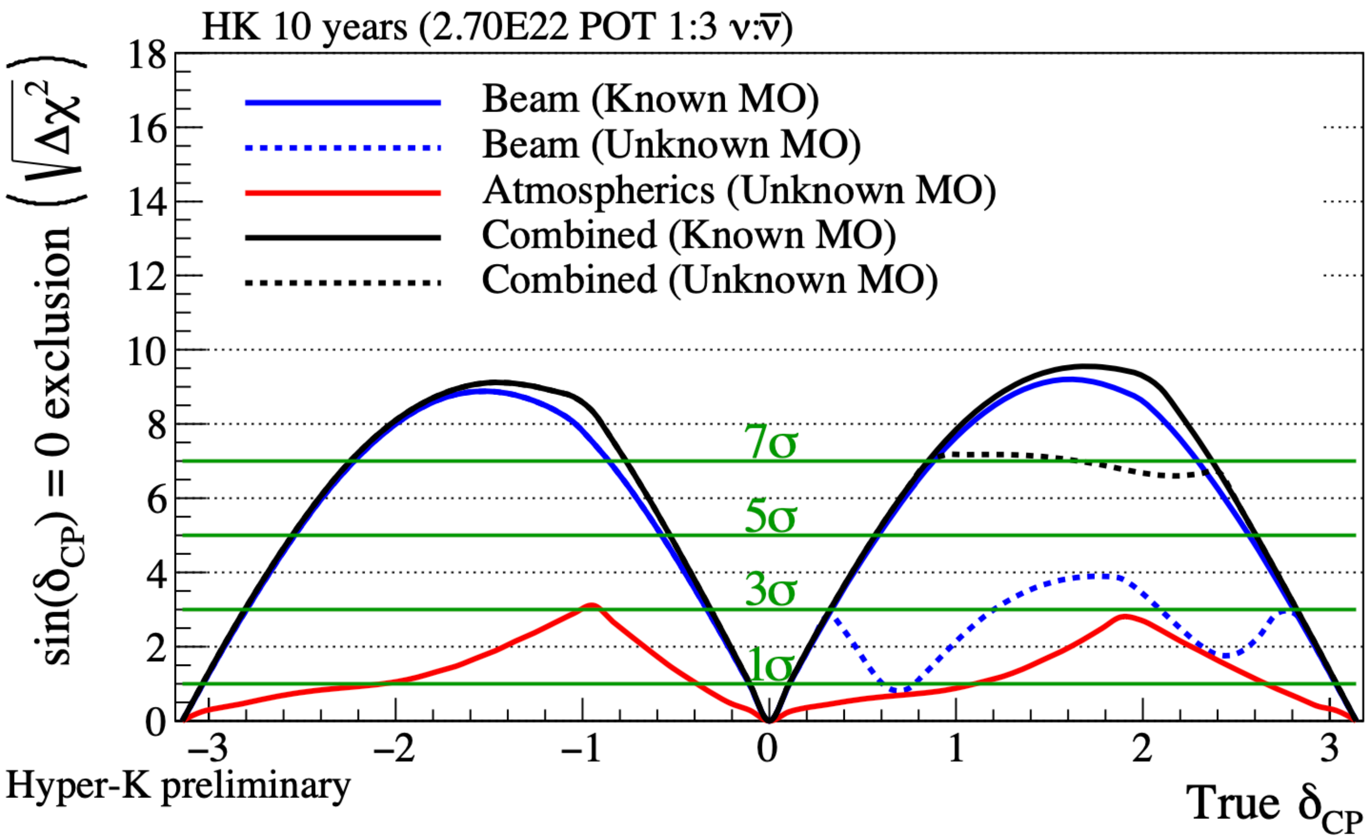
✓Additional water Cherenkov detector at the near site (~800m)

Comparison with T2K before long shut down:

$\times 2.5$ beam power and $\times 8$ target mass

$\Rightarrow \times 20$ more data





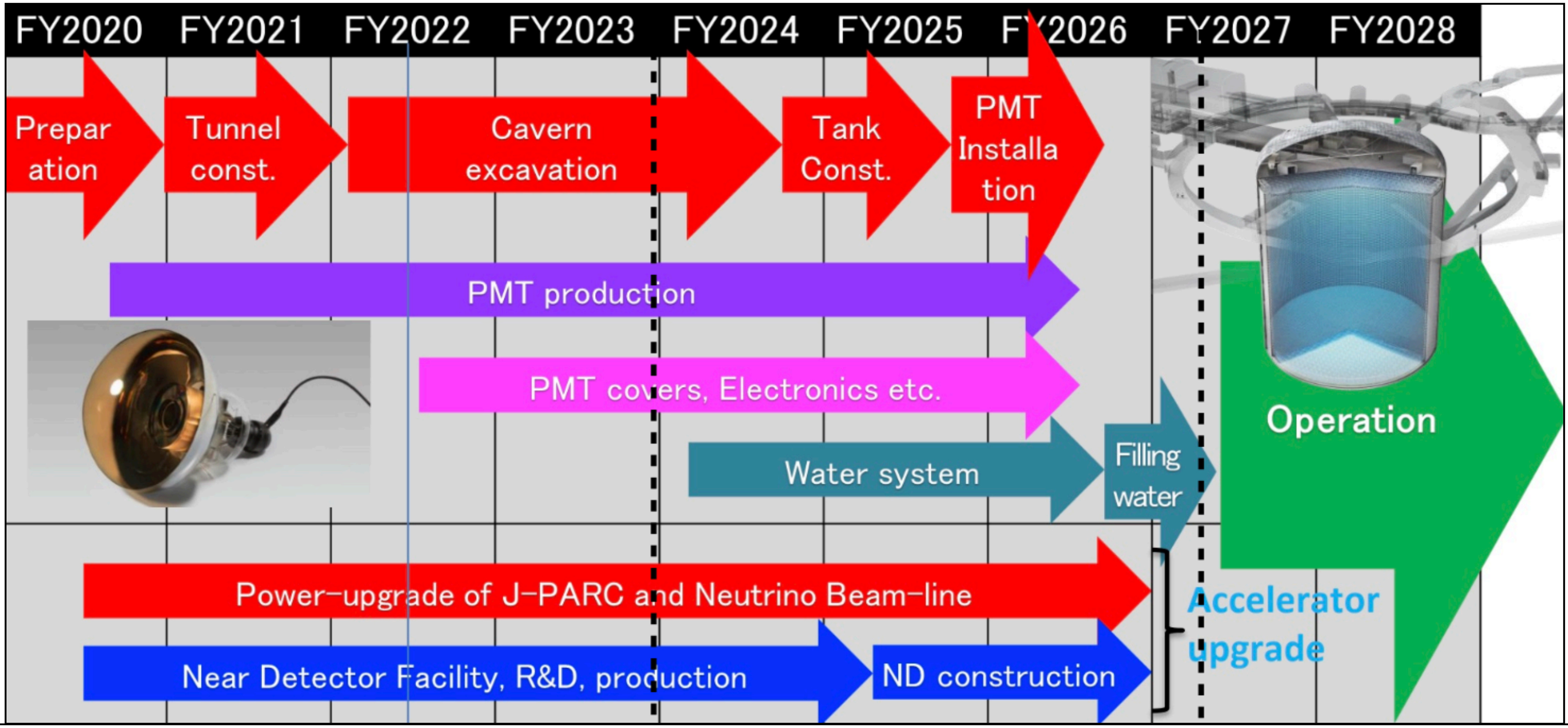
Discovery of CP violation for a wide range of δ_{CP} values

4-6 σ sensitivity to Mass Ordering (accelerator+ atmospheric ν data)

"Non-oscillation" major goals: proton decay search, Supernova relic ν

The Hyper-K schedule

- Mass production and construction are ongoing
- Data taking for physics measurements with accelerator & atmospheric neutrinos in 2027

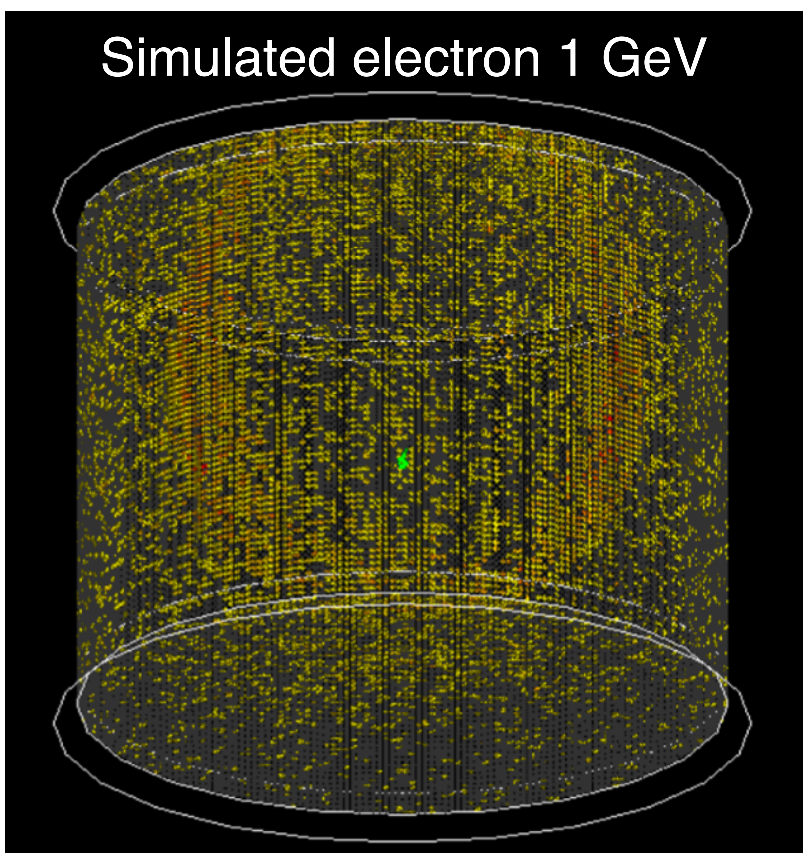


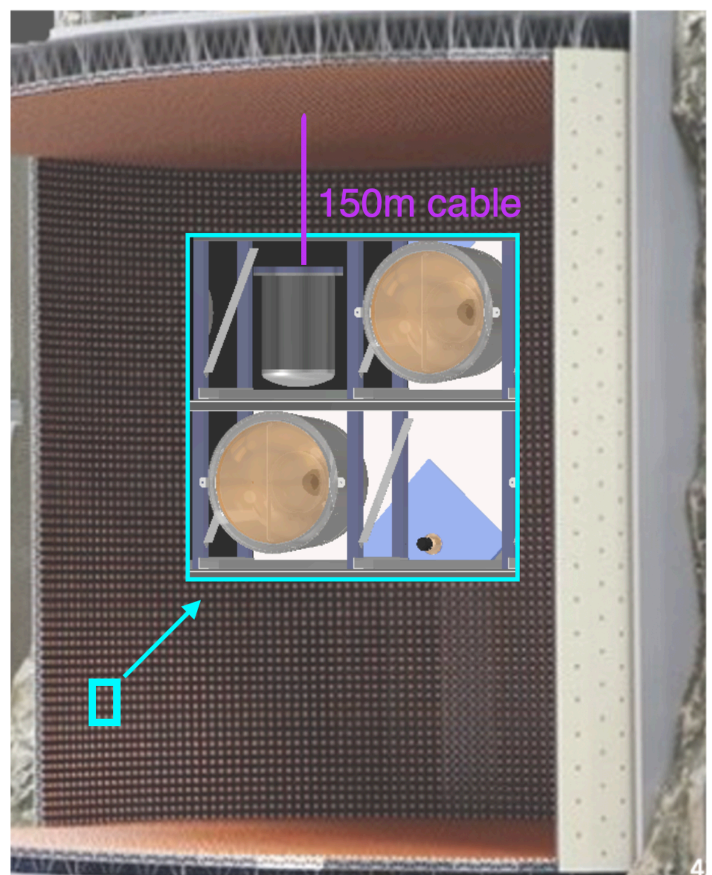
The Far Detector front-end electronics

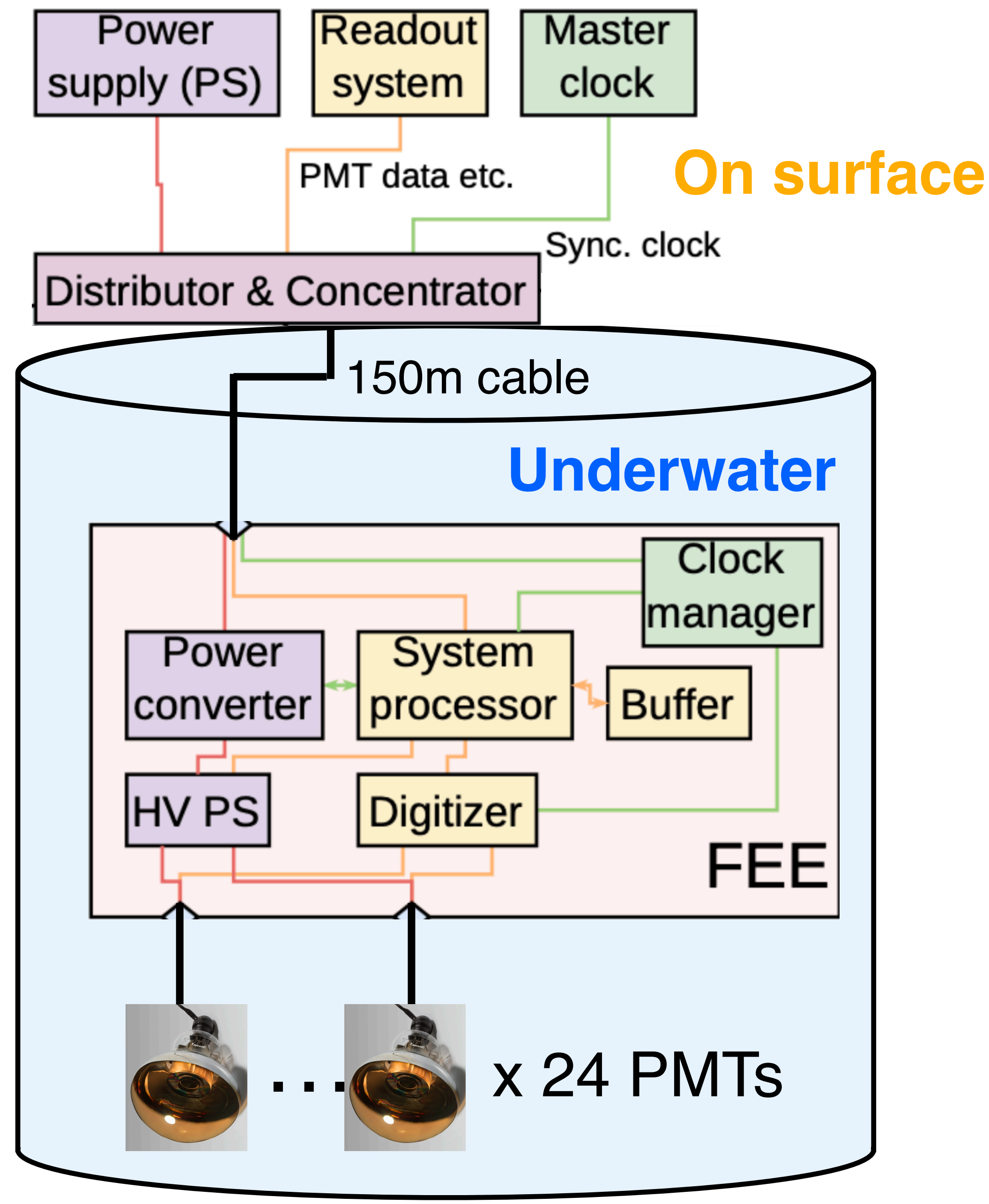
Cherenkov light produced in pure water and read out PMTs

- Inner Detector (ID): ~20,000 PMTs $\Rightarrow$ ν interactions in Fiducial Volume
- Outer Detector (OD): ~3,600 PMTs $\Rightarrow$ veto background cosmics

~900 underwater units to supply the voltage to 23,600 PMTs and digitise the analogue signal





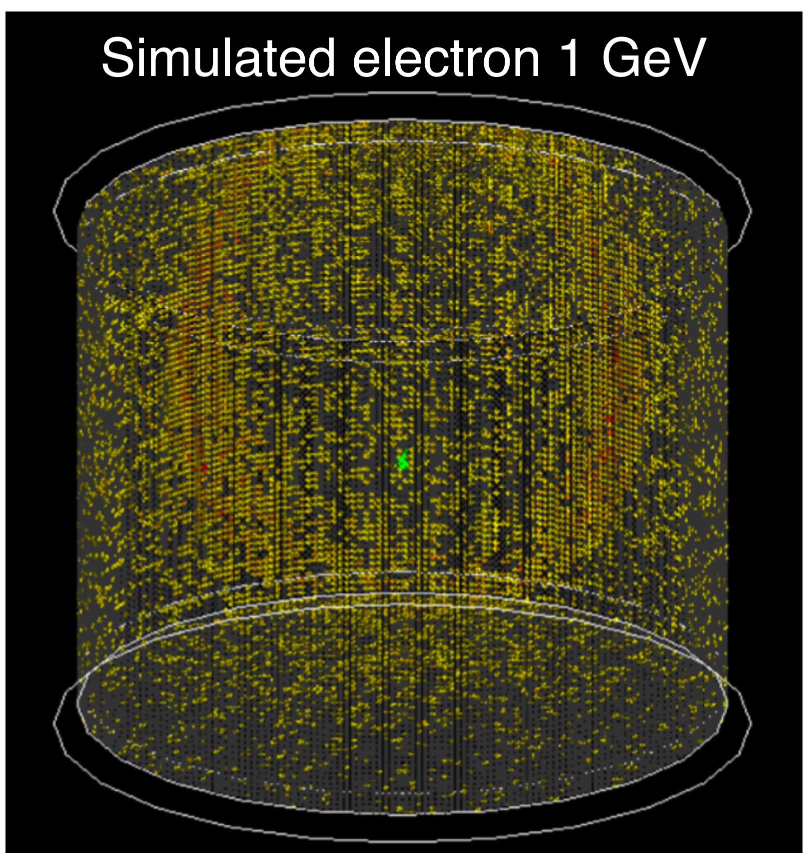


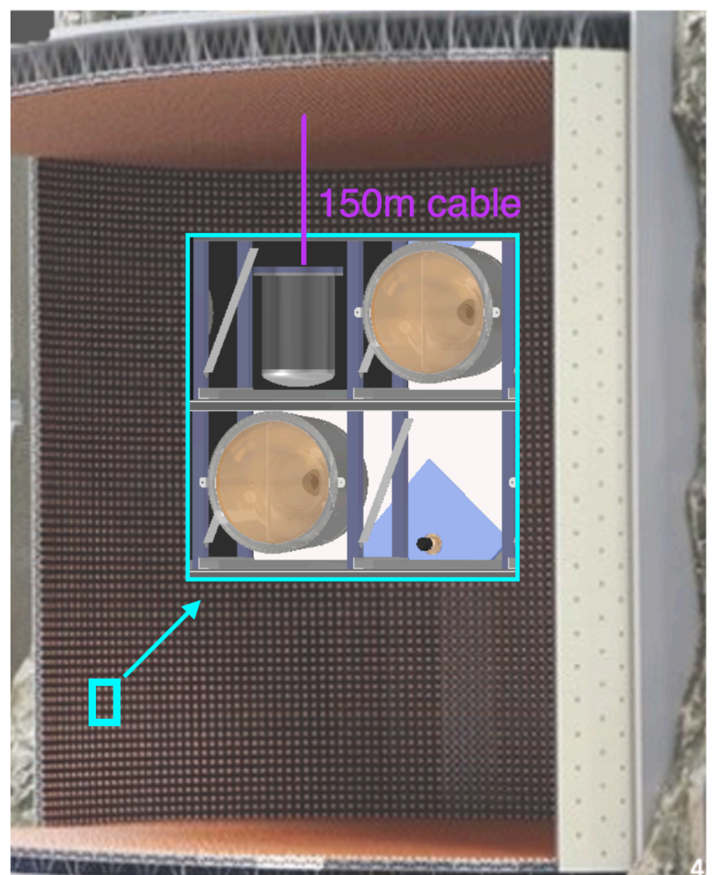
The Far Detector front-end electronics

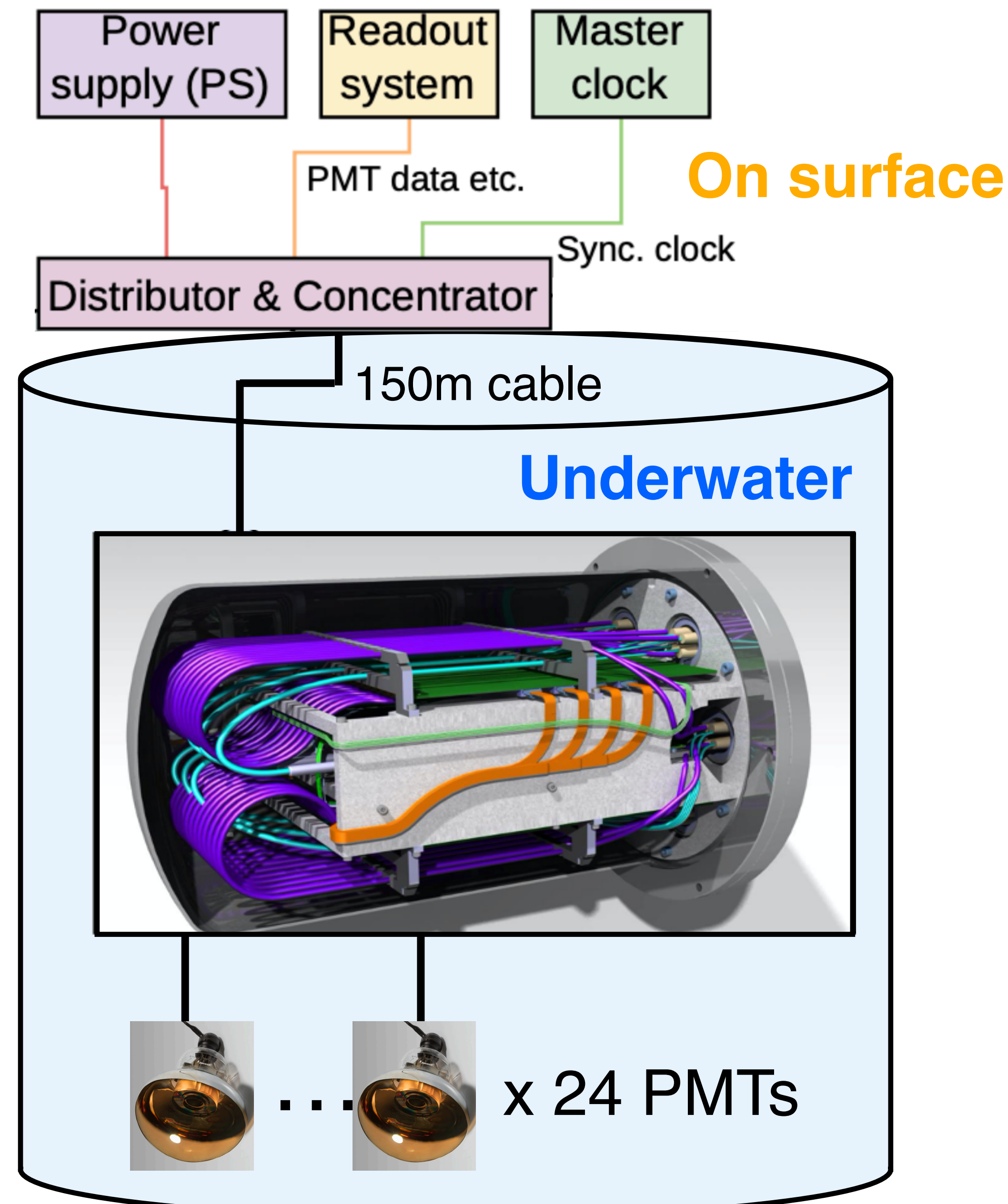
Cherenkov light produced in pure water and read out PMTs

- Inner Detector (ID): ~20,000 PMTs ⇒ ν interactions in Fiducial Volume
- Outer Detector (OD): ~3,600 PMTs ⇒ veto background cosmics

~900 underwater units to supply the voltage to 23,600 PMTs and digitise the analogue signal





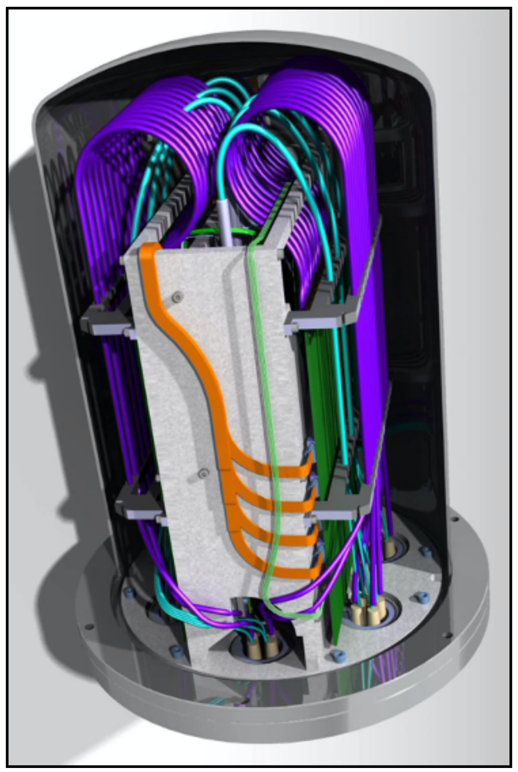


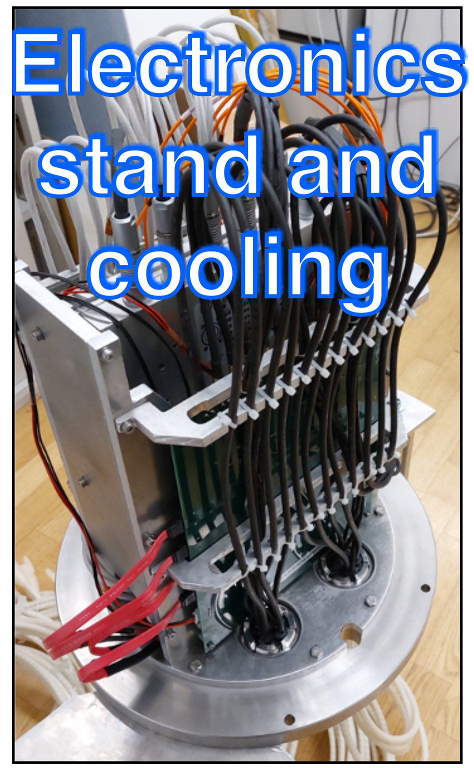
Electronics mass production

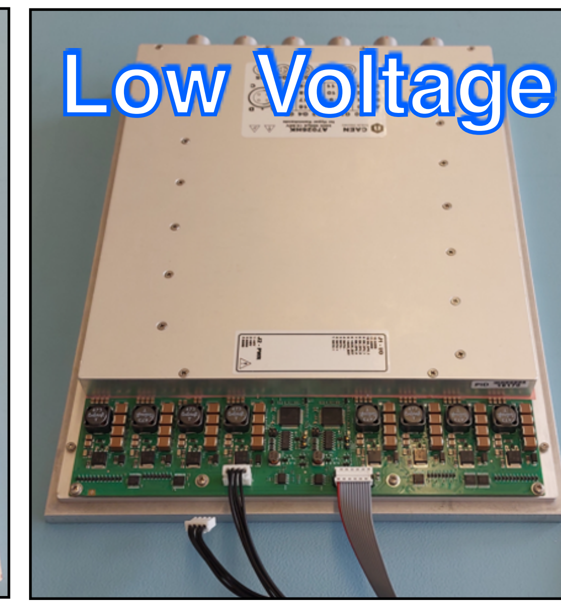
FLARE 23-24 funded

Major responsibility on the underwater unit design and production:

- Eng Gendotti (ETHZ) mechanics convener, Dr Kose (ETHZ) HV/LV convener







- Mass production funded with FLARE 24-25 ⇒ 4.4 MCHF

  ✓Status of HV and LV module production
  ⇒ tender with CERN finalised, started pre-series production

  ✓Status of mechanical vessel production
  ⇒ tender launched with ETHZ, start mass production in Summer

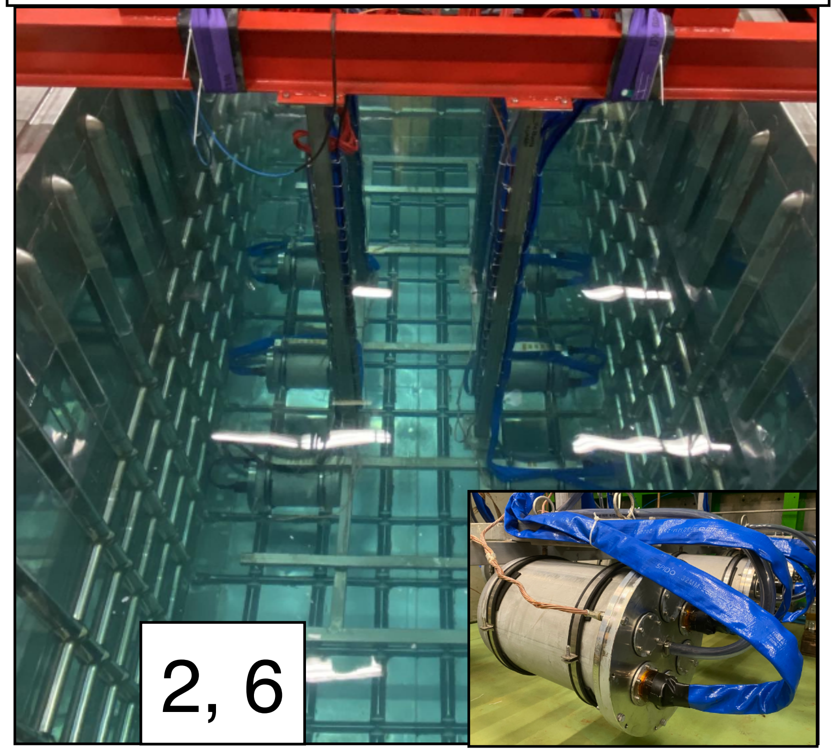
Electronics assembly at CERN

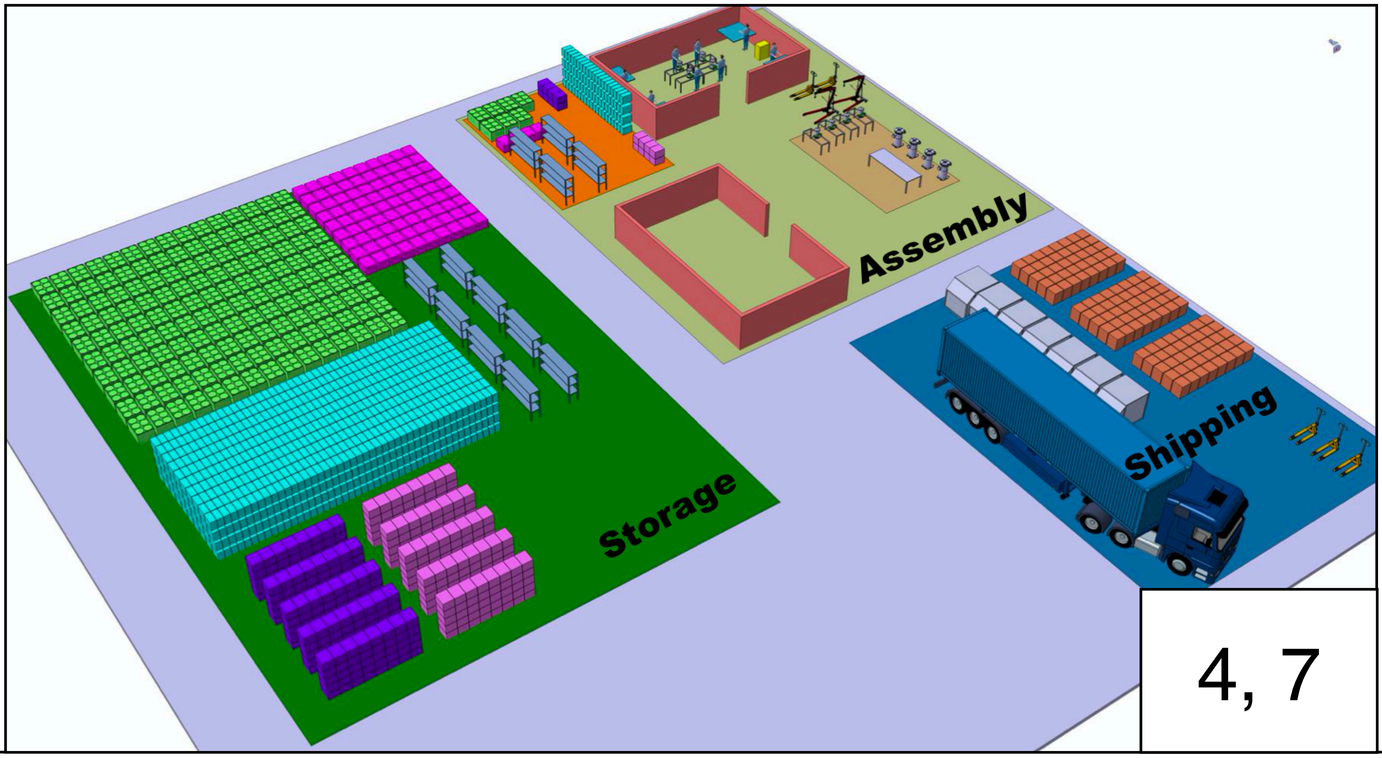
FLARE 25-26 to request

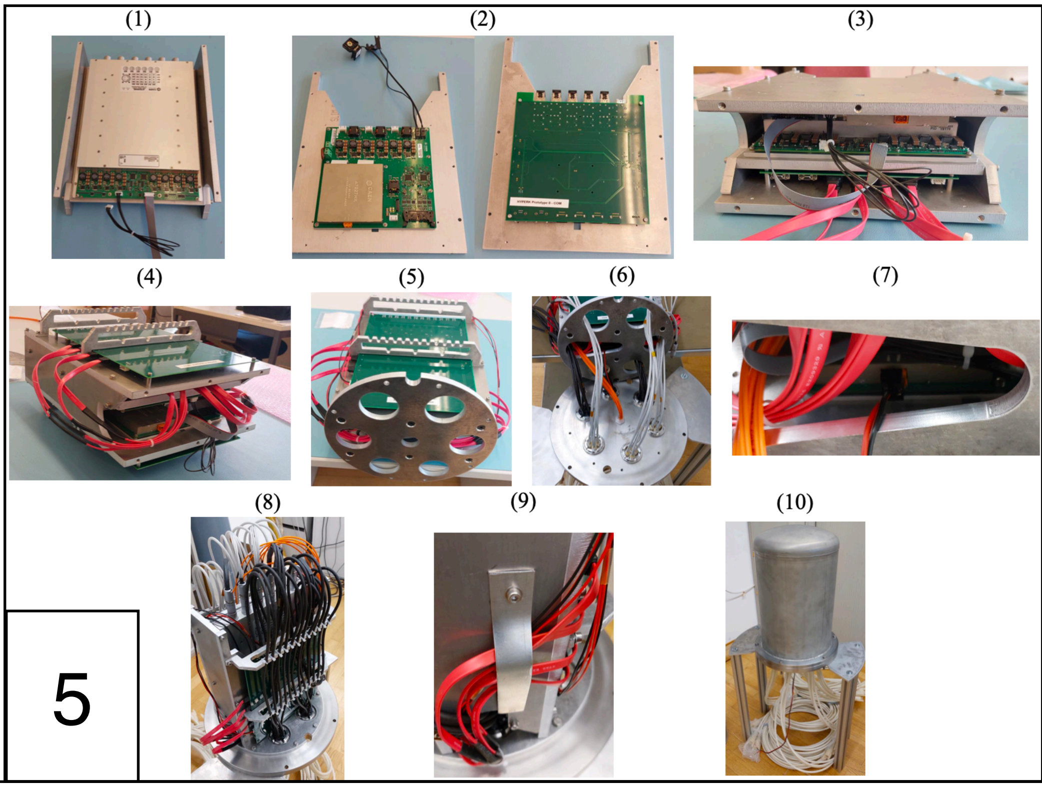
The project comprises different activities:

1. Vertical Slice tests (ONGOING)
2. Long-term prototype tests in water (ONGOING)
3. Design Testbench for digitizer calibration before assembly and tests during assembly (ONGOING)
4. Assembly of the 900 underwater units
5. Test each unit in water at high-pressure
6. Long-term electronics test (during assembly)
7. Shipment of 900 units to Japan

Tests in WA105 cryostat@CERN





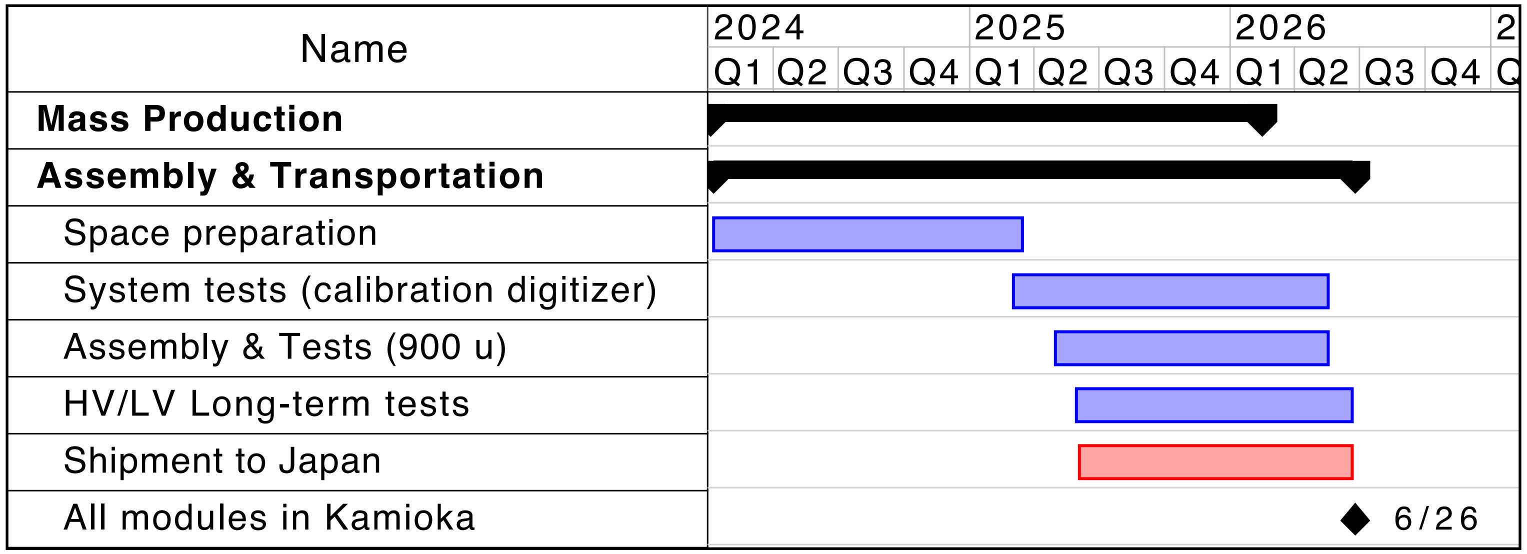


Electronics assembly at CERN

FLARE 25-26 to request

- Letter of Intent submitted to CERN SPSC CERN-SPSC-2023-021 (SPSC-I-260)
  - ✓23 institutes, 106 collaborators
  - ✓Project proposed to be within the framework of the Neutrino Platform
  - ✓Prof. D.Sgalaberna (ETHZ): spokesperson of the project collaboration
  - ✓Dr. U.Kose (ETHZ): technical coordinator
- Total of 3 MCHF will be requested in FLARE 25-26
  - ✓technicians for assembly (delicate steps to ensure water tightness)
  - ✓equipment / storage costs
  - ✓logistic + shipment to Japan

The project shall start in 2025 for ~1.5 years



Mechanical integration at FD

FLARE 25-26 to request

- After the assembly and test, the electronics units will be shipped to Japan and integrated in the Far Detector tank

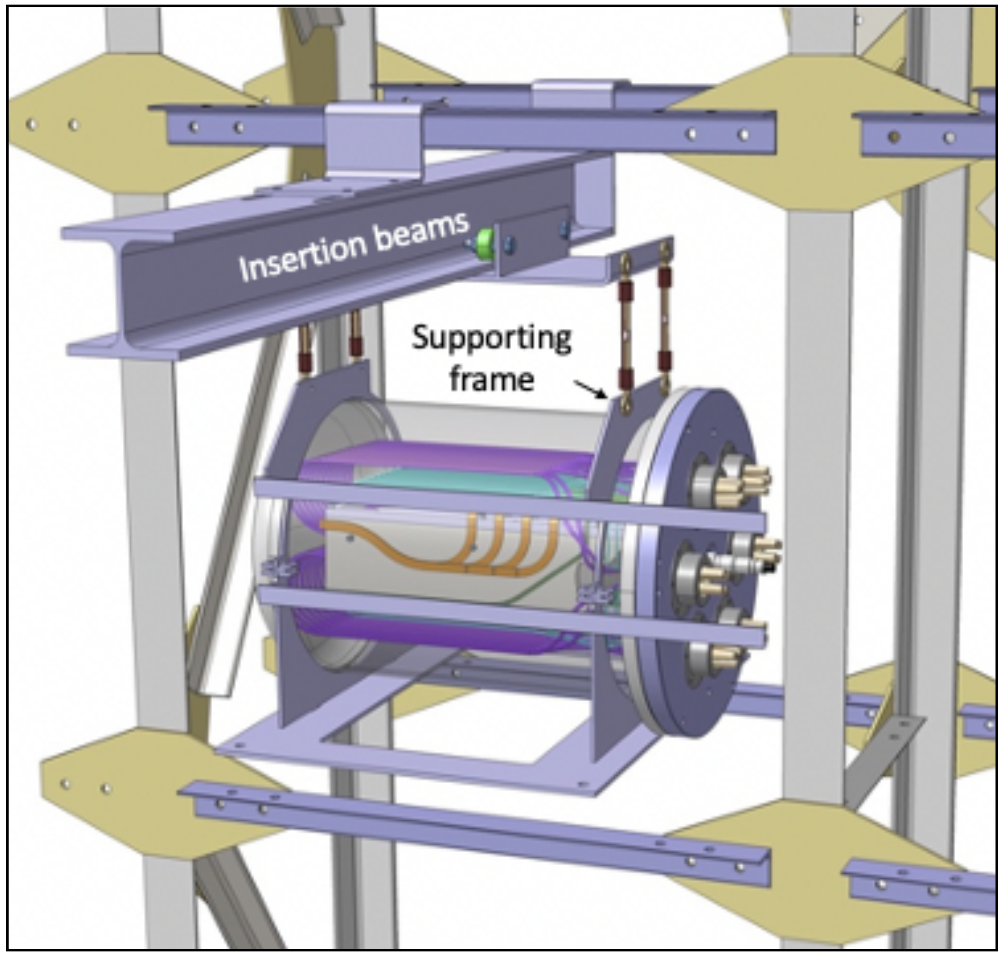
- Swiss tasks:

  ✓mechanical vessel integration design

  ✓simulation of the deformation and stresses of the support structure (installation in air and operation in deep water)

  ✓insertion beams at the top of the support structure housing the vessel

  ✓definition of the installation procedure



- Eng F.Cadoux (UniGe): responsible for the vessel mechanical fixation

FLARE 25-26 request to also cover the costs related to mechanical integration at the Far Detector

δ_{CP} precision measurement

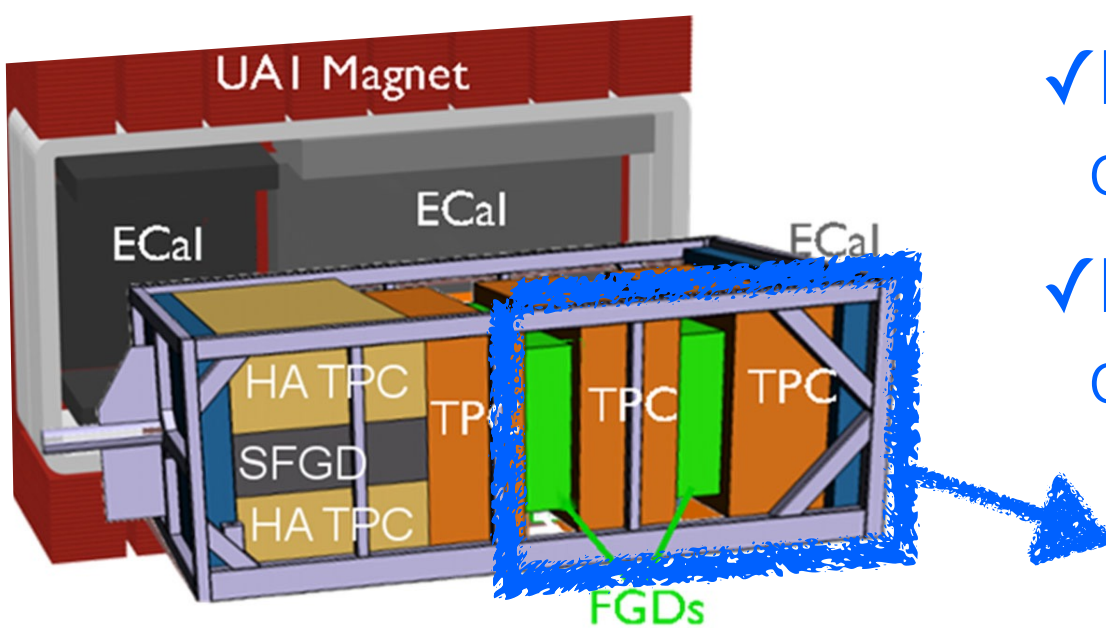
FLARE Beyond '27

Hyper-K Near Detector: ND280 + Intermediate Water Cherenkov Detector
⇒ sufficient for early phase. To improve our control on systematics we need:

1. Precise cross section measurement in water (ν_μ vs $\bar{\nu}_\mu$)
2. $\sigma(\nu_e)/\sigma(\nu_\mu)$ and $\sigma(\nu_e)/\sigma(\bar{\nu}_e)$ down to theoretical uncertainties ~3%
3. Resolve nuclear processes in ν-nucleus interactions
   - ✓Efficient neutron detection with TOF measurement (pure $\bar{\nu}$-H sample)
   - ✓Reconstruction of low-momentum protons below 300 MeV/c

⇒ 3D-grained & massive & water content & calorimetry & sub-mm tracking

ND280 complex



Ensure the functioning of the "old" detectors (operating since 2010)

✓Prof. Sanchez (UniGe) convener of Hyper-K ND280 WG

✓Prof. Sgalaberna (ETHZ) convener of T2K ND280 Physics WG

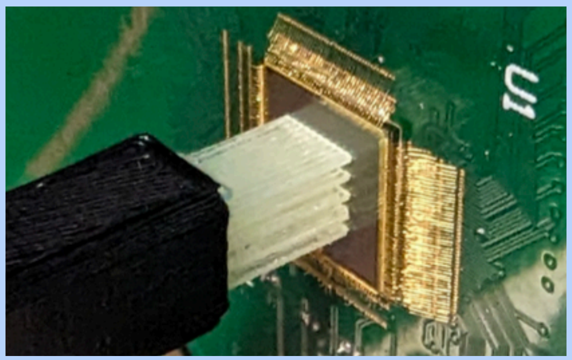
Volume taken by "old" detectors can be filled with ~10 tonnes of water/organic target

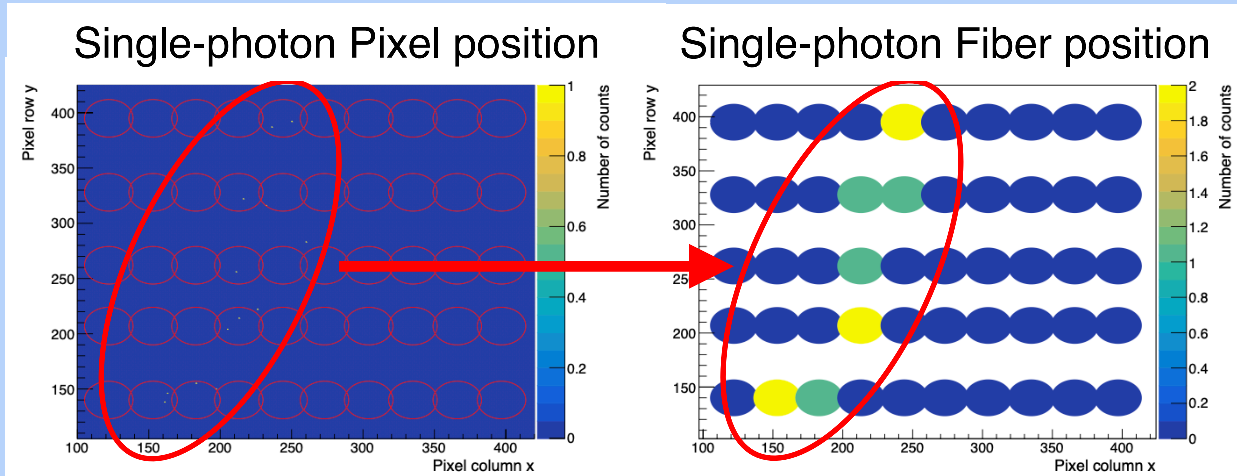
Status of the R&D

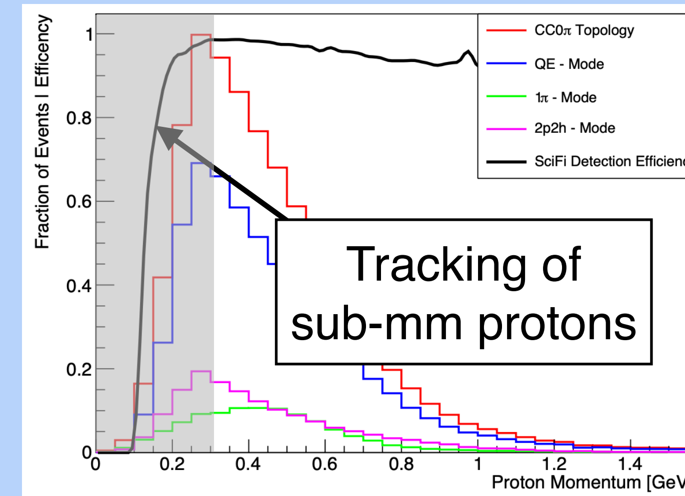
FLARE Beyond ‘27

Sub-mm tracking scintillating fiber active target read out with SPAD arrays

Sgalaberna, Charbon (EPFL) et al. arXiv:2309.03131

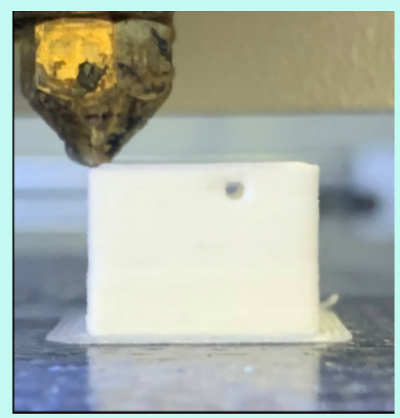


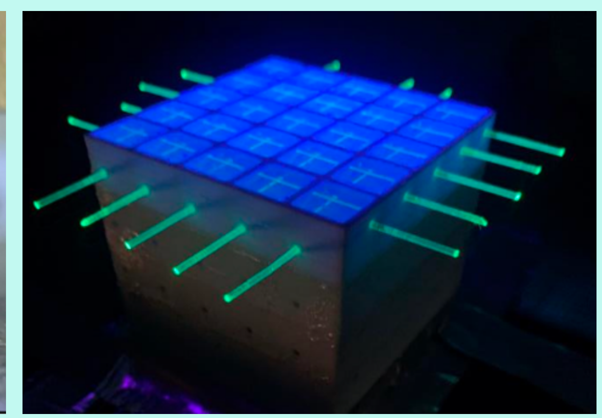


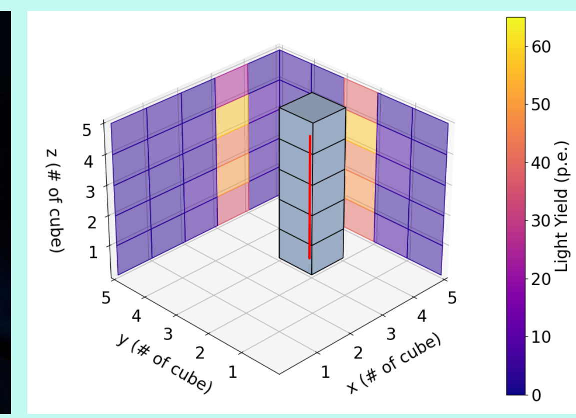


3D printing of large volumes of highly segmented scintillator

Sgalaberna, Rubbia et al.
(3DET R&D collaboration)
arXiv:2312.04672

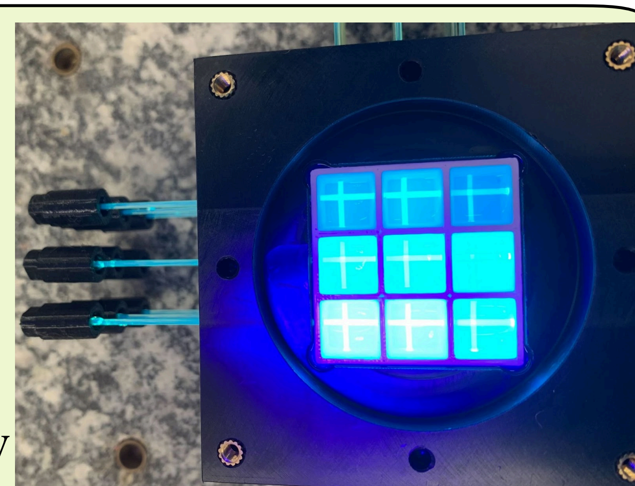






3D segmented Water-based Liquid Scintillator detector

Collaborating with Brookhaven National Laboratory



R&D will continue for the next 2-3 years to improve the performance

Freeze design with collaboration approval in 2026-2027 and move to construction

Swiss roadmap for ν experiments in Japan

	Schedule and FLARE funding requests									
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Budget (MCHF)	4.4 (APPROVED)		3		3		1		0.5	
T2K	Operation									
HK FD	Construction				Operation					
HK ND upgrade	R&D			Design	Construction			Operation		

- Well-defined roadmap towards the CP phase precision measurement and the Mass Ordering determination with discovery potential already by 2030
- The flagship status has been supported by SNSF with important contributions
- Swiss contribution is crucial and is endorsed by key roles
- Future FLARE calls will see a gradual decrease in the budget request