Hyper-K Instrumentation Highlights

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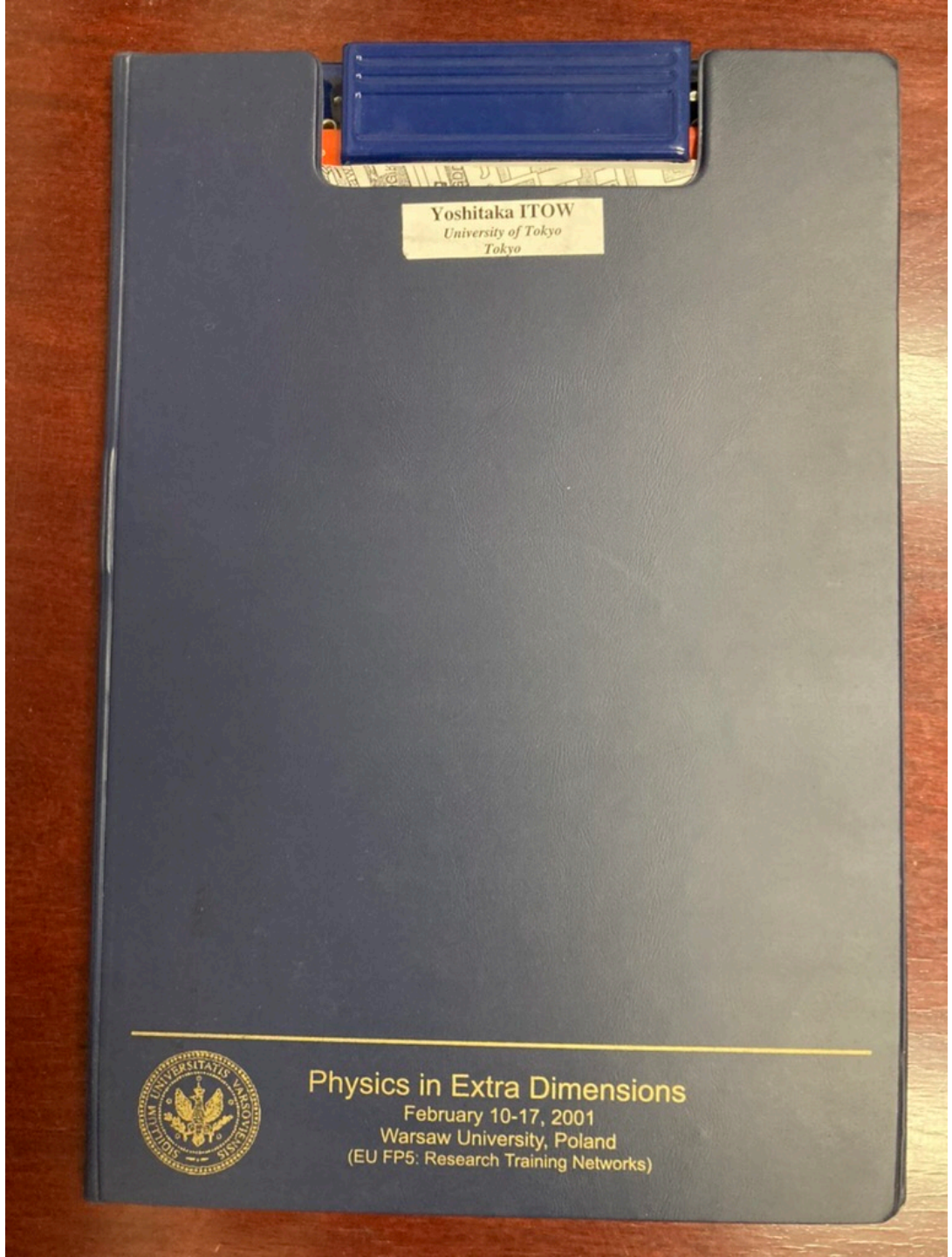
II EU Workshop on Water Cherenkov Experiments for Precision Physics
2025 September 19th

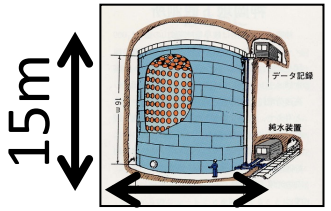

Yoshitaka ITOW
University of Tokyo
Tokyo
Physics in Extra Dimensions
February 10-17, 2001
Warsaw University, Poland
(EU FP5: Research Training Networks)

From Kamiokande to Super-K, and Hyper-K FD

45 years legacy of underground water Cherenkov detectors at Kamioka mine

- Factor 2 scale-up, one-order larger FV masses than Super-K
- Basic technology is same, but many new challenges in Hyper-K construction

1983-1996

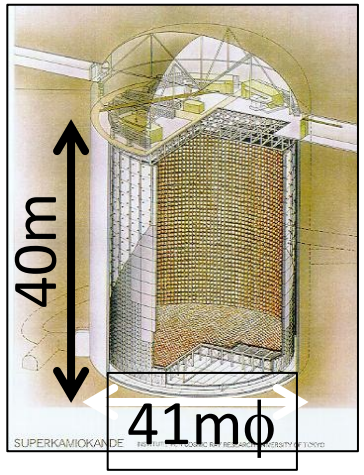


Kamiokande

3kt / FV 1kt

1000 20"-PMTs

1996-



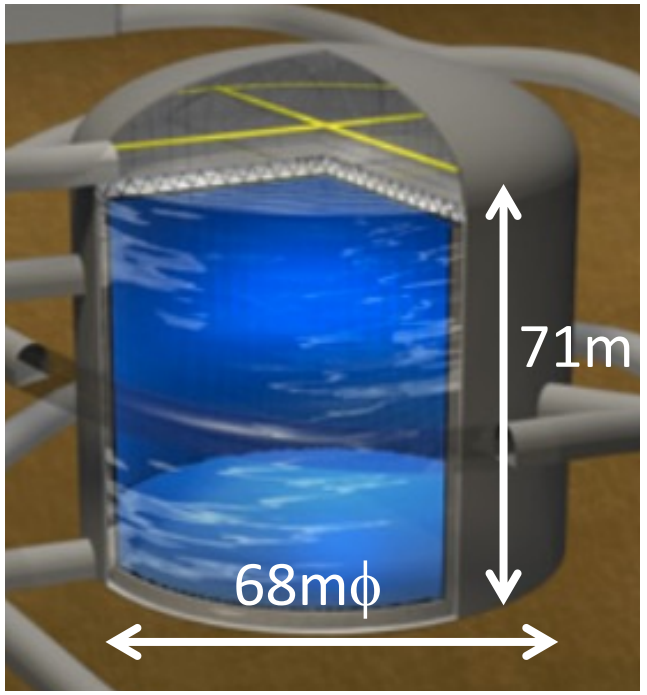
Super-Kamiokande

50kt/ FV 22.5kt

11,000 20"-PMTs)

SK-Gd (2020-)

2028-



Hyper-Kamiokande (FD)

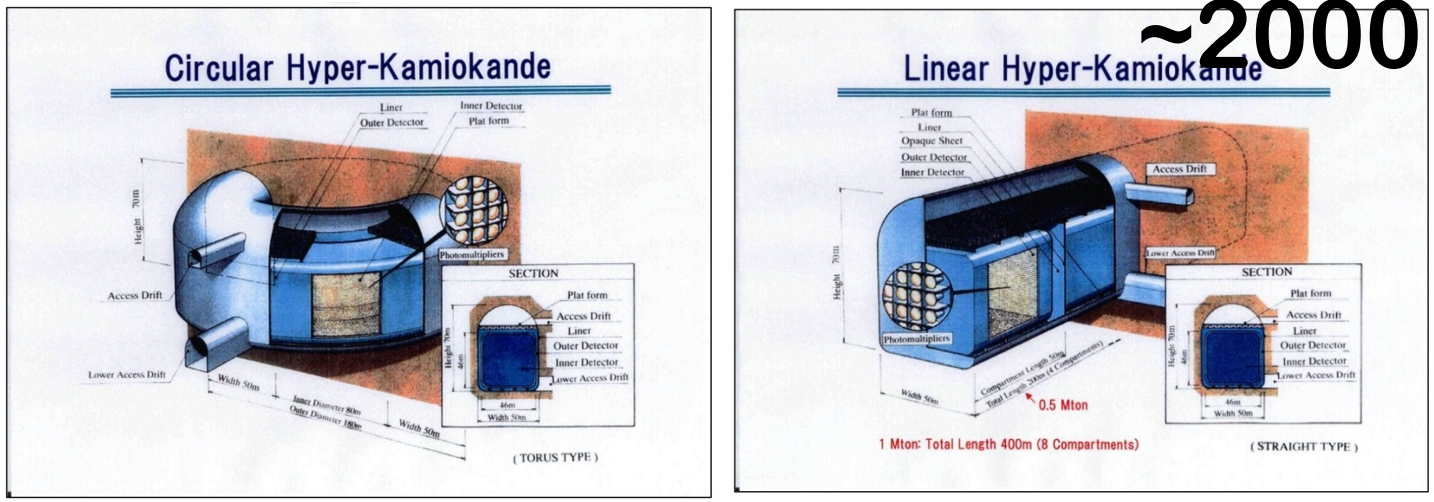
260kt / FV 186 kt

20,000 20"-PMT + 800 mPMTs

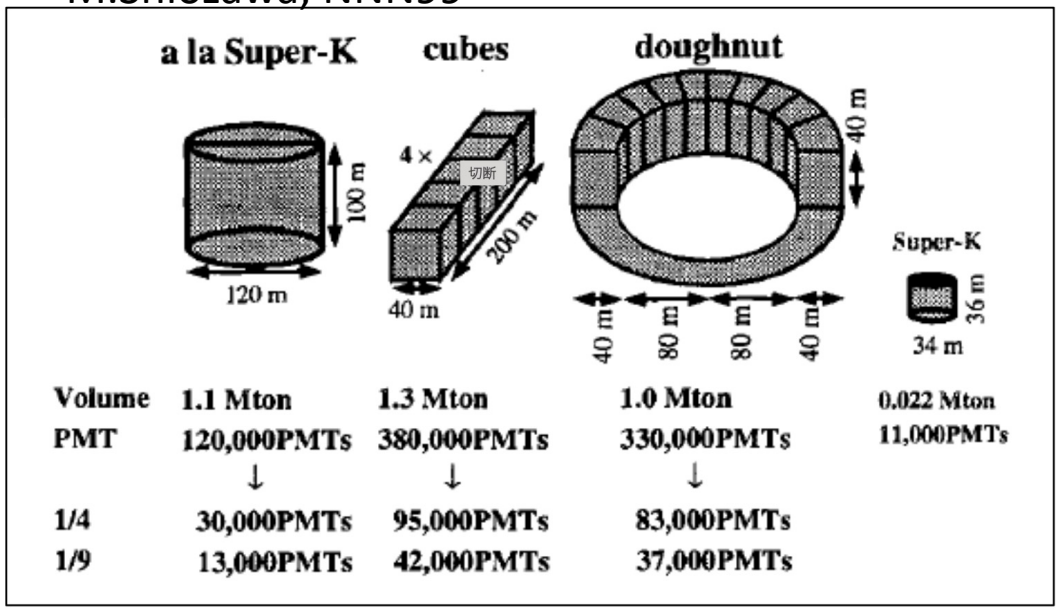
Many years of consideration until the final design…

- 30mϕ Donuts rings (M. Koshiba, Phys. Rep. 220 (1992) 229)

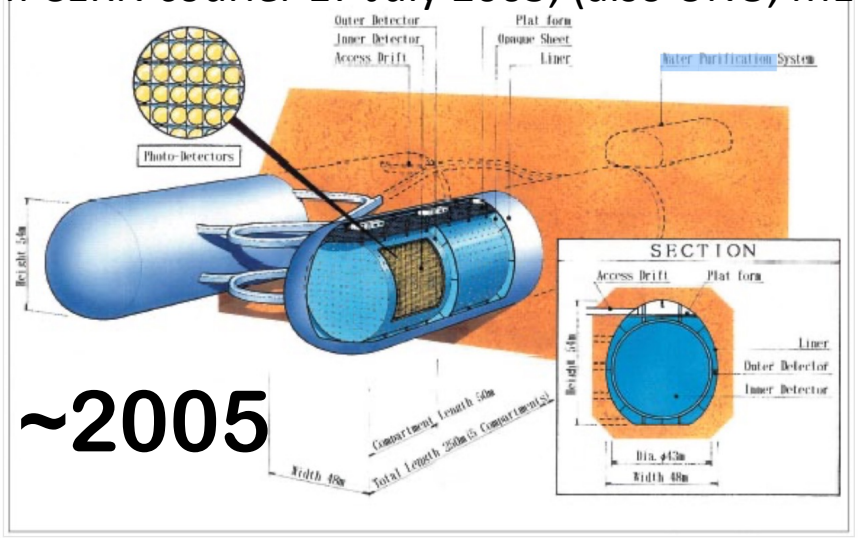
K.Nakamura and M.Shiozawa, NooN2000

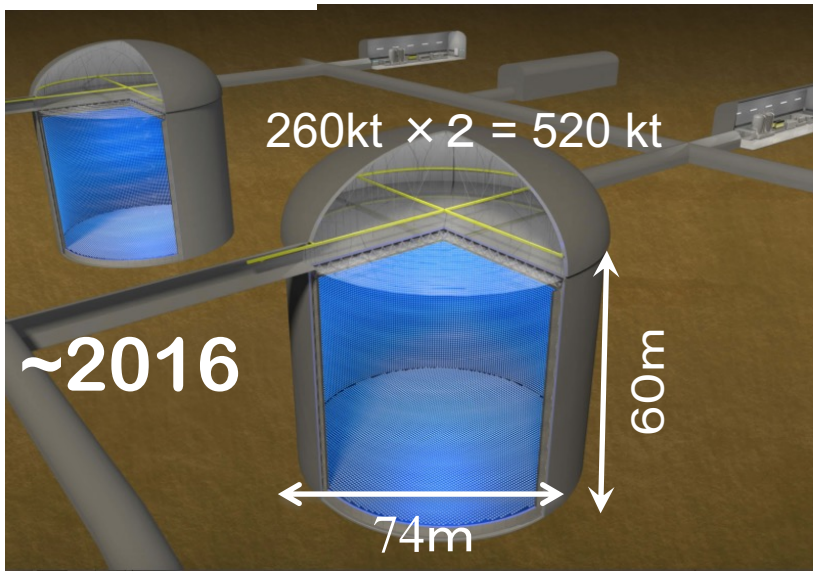


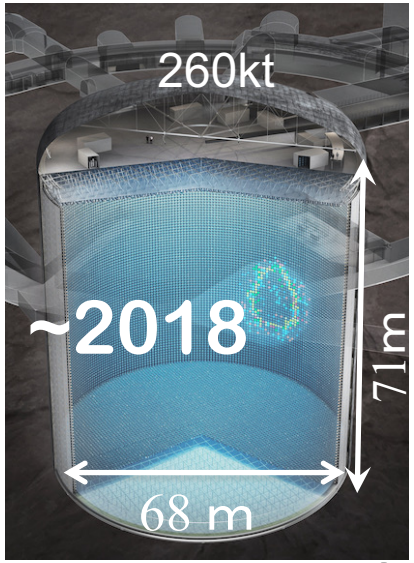
M.Shiozawa, NNN99



From CERN courier 17 July 2005, (also UNO, MEMPHYS)

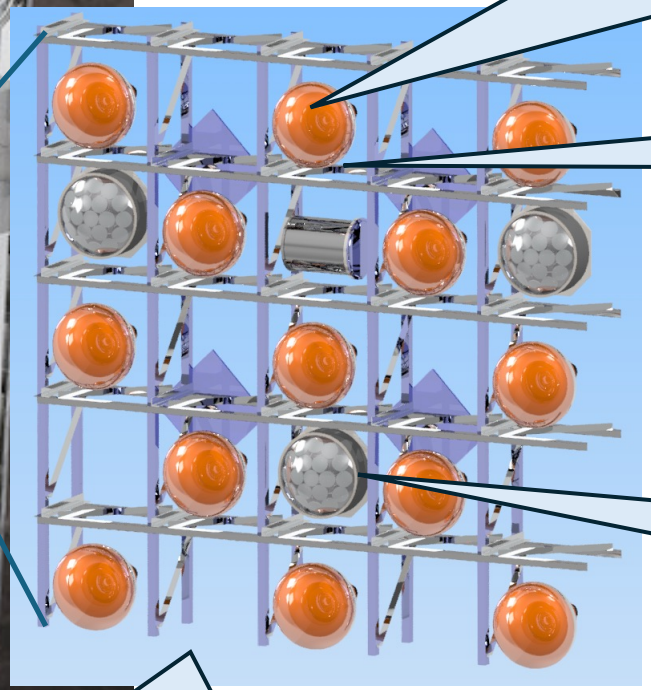




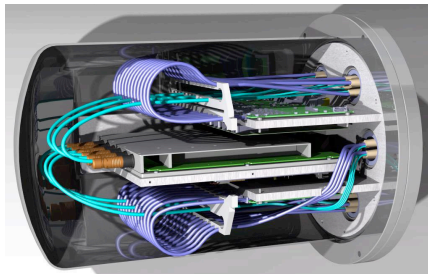


New Challenge in Hyper-K Far Detector instrumentation

A new 50cm-PMT with doubled PDE and pressure tolerance



Underwater electronics



mPMT with 19 3”PMTs

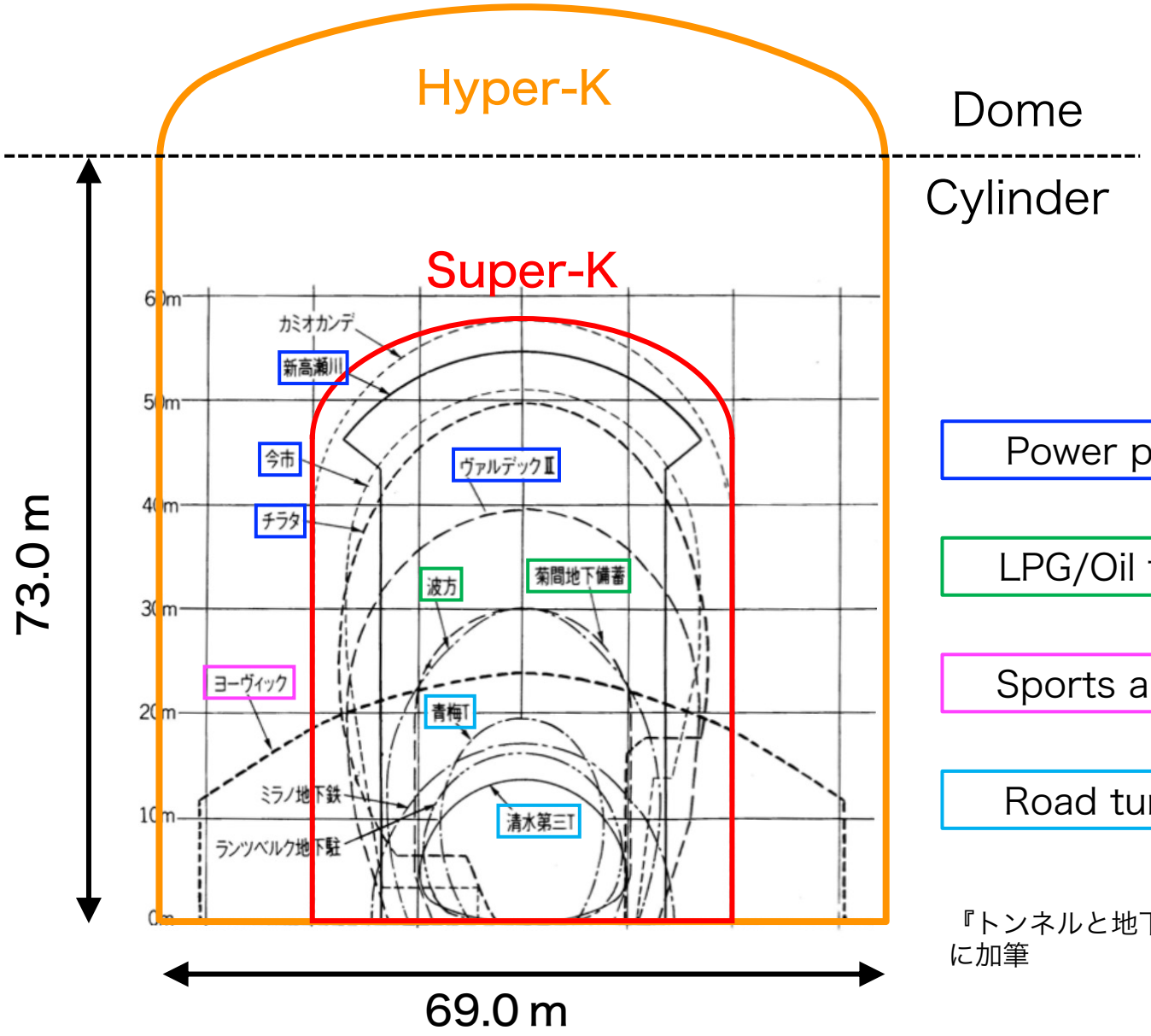
Detector integration

Excavation of Hyper-K cavern

Oct 2023 Dome excavation completed

June 2025 Entire cavern completed

The single cavern with the largest span ever

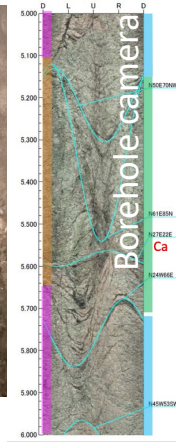


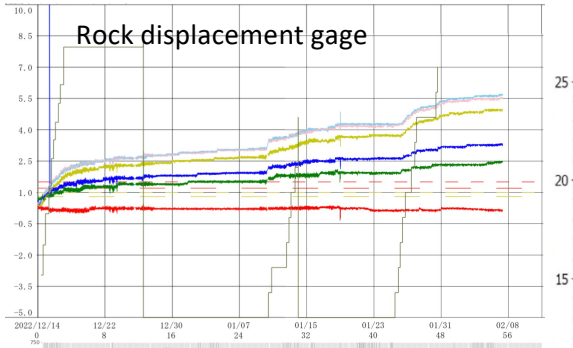
『トンネルと地下』1998年7月号（土木工学社）に加筆

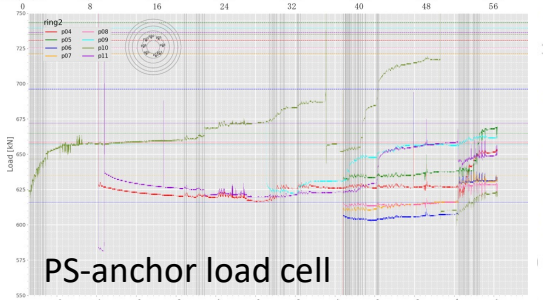
H. Tanaka

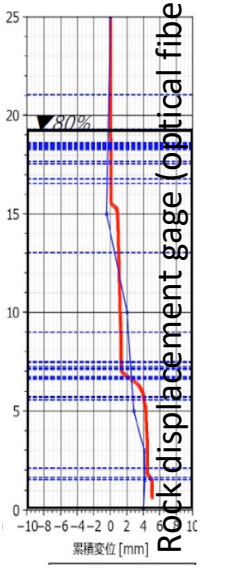
A key of the HK cavern excavation

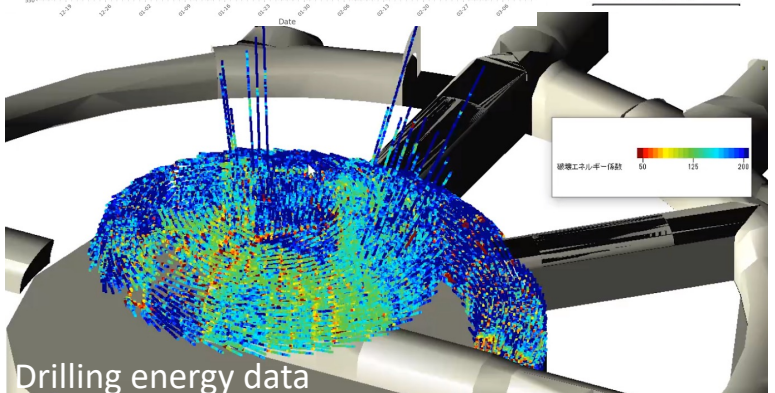
- **Information-oriented design and excavation**
  - More than 200 monitoring devices installed in the cavern and continuous monitoring of bedrock behavior
    - Ensure the stability of the cavern and safety in the excavation work
    - If an anomaly is detected by the monitoring devices, additional bedrock support and safety measures were implemented
  - The geological model for the cavern stability analysis is continuously updated based on various geological information obtained during the progress of excavation work, e.g., geological inspection, borehole camera data, drilling energy, etc.
  - By integrating all of these information, the bedrock support design and excavation procedures are continuously optimized







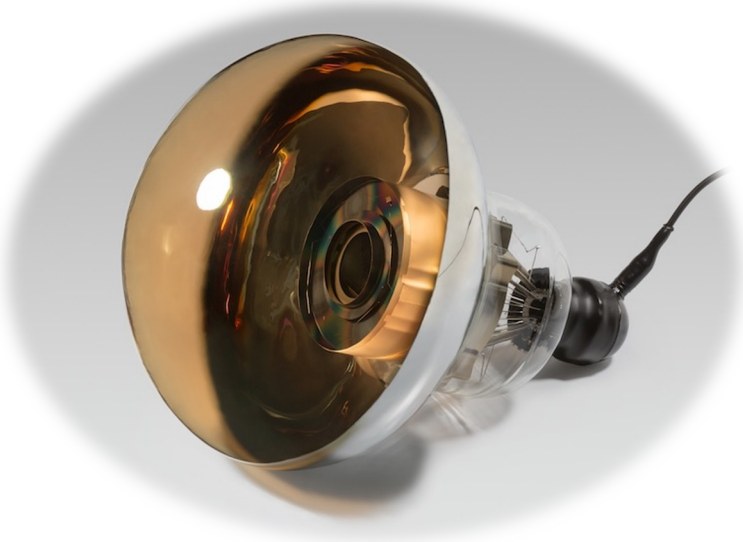




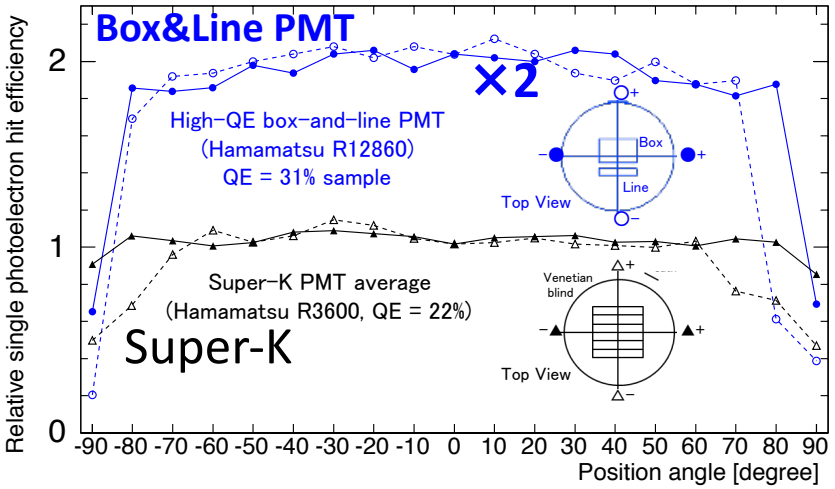
Y. Nishimura

A new 50cm Box-Line PMT (R12860HQE)

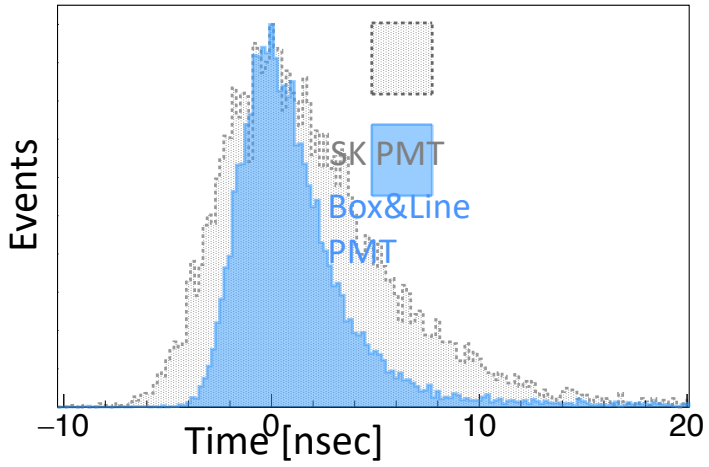
- High QE / CE Box-Line type PMT (x2 Super-K PMT)
- Reduction of dark rate (<4kHz in water)
- Improved charge/timing resolution
  - ΔT 7.3ns →4.1 ns, 1PE σ/mean : 53%→35%
- High water pressure tolerance
  - Key to realize the 70-m depths of tank
  - Ensure no damage up to 1.25 MPa (0.6 MPa : Super-K PMT)



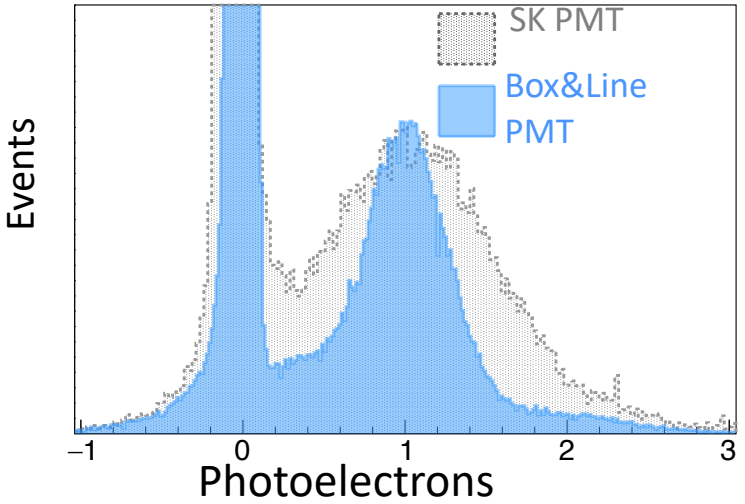
Total Detection Efficiency of 1 PE



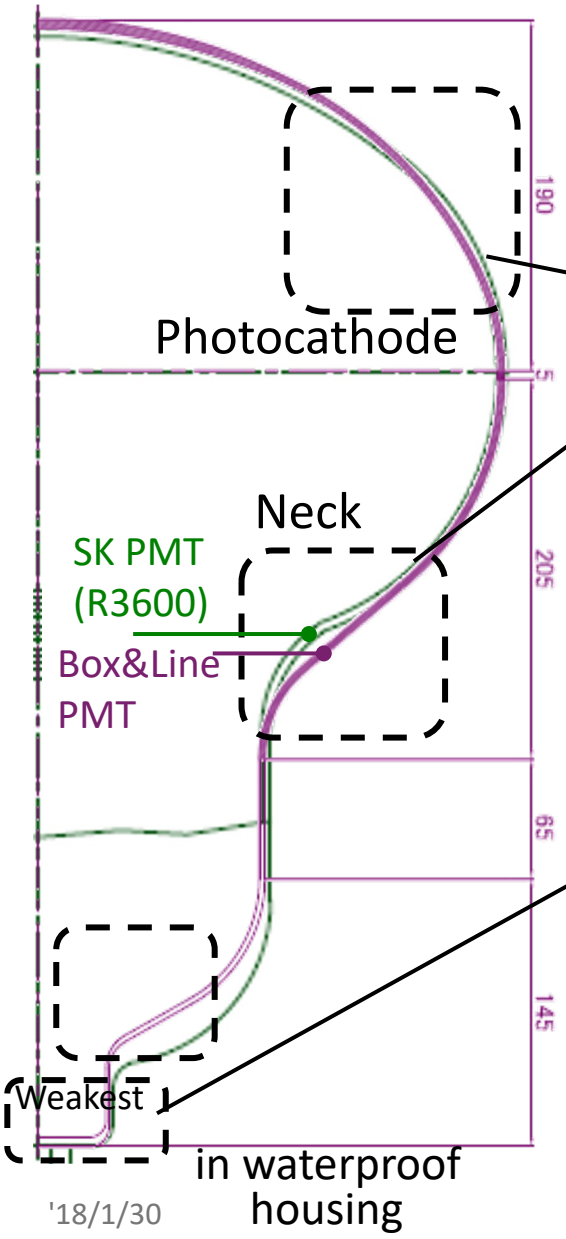
7.3ns → **4.1ns FWHM**



53% → **35%σ**



Improvement of water pressure tolerance



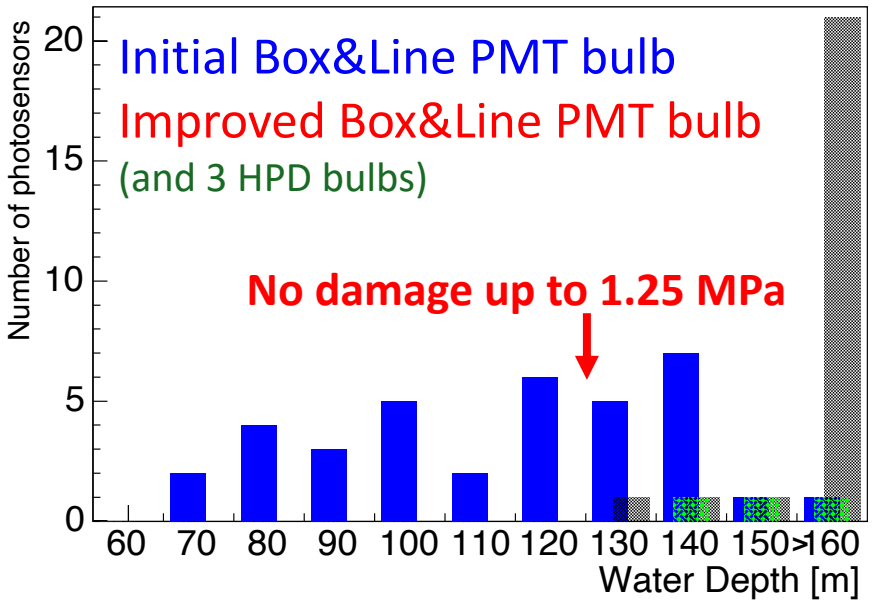
The bulb shape was designed to get lower tensile stress for deeper water.

- Smoother curvature
  - < 1/16 stress
  - (weakest in SK PMT) < 1/8 stress
- Thicker glass (about ×1.3)
  - Because of correlation confirmed with breaking level by test
  - New criteria on quality control was established with measuring thickness at various points.
- Tough waterproof housing

Super-K ASSY

Hyper-K ASSY

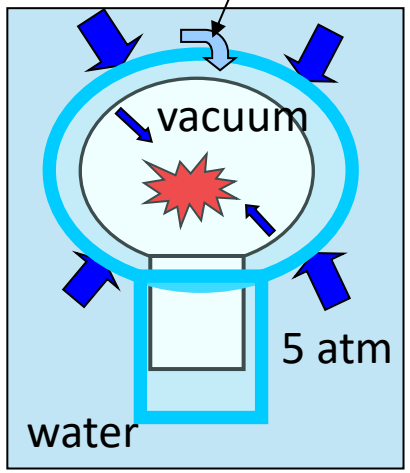
Test with a pressure vessel

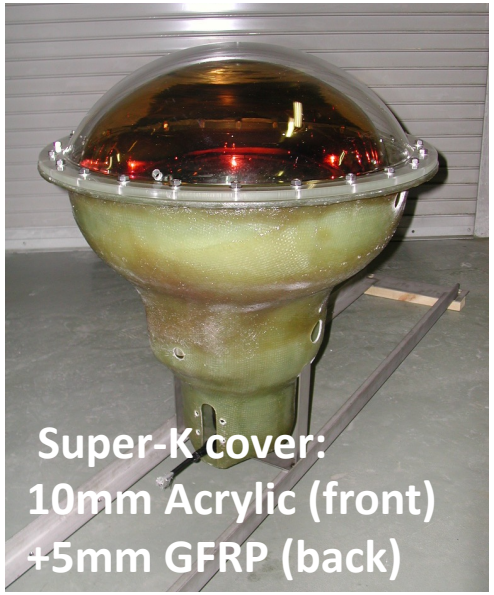


Anti-implosion PMT covers to prevent chain reaction

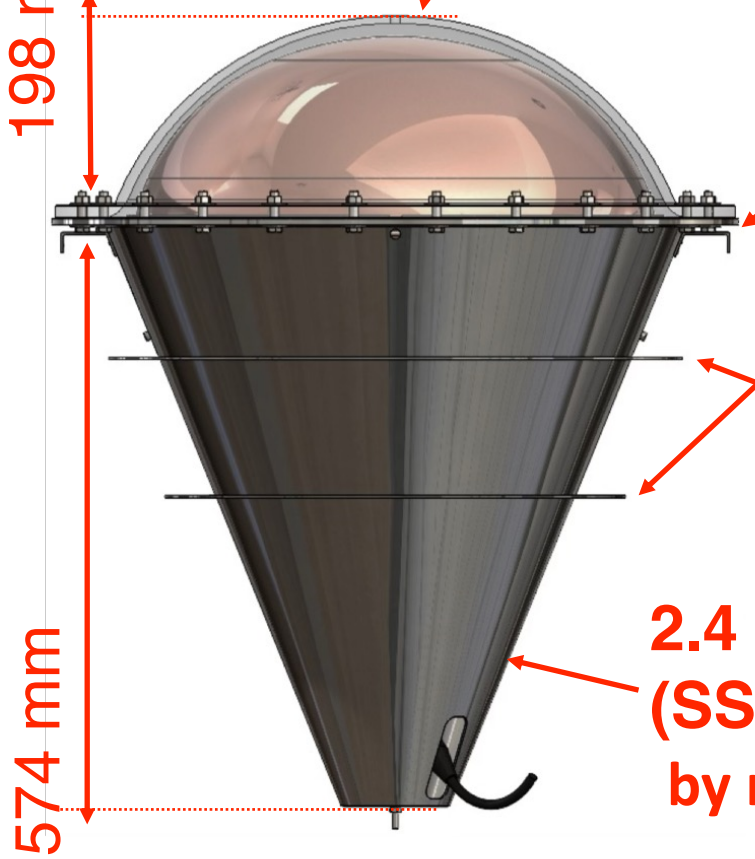
Promoted by Spanish institutes

Reduce water flow speed
(~1 ms → ~1 s)





Hyper-K cover:



- >66% @ λ=300 nm
- >90% @ λ=400 nm

Flange coupling
acrylic: 13mmt
SUS: 6 mmt

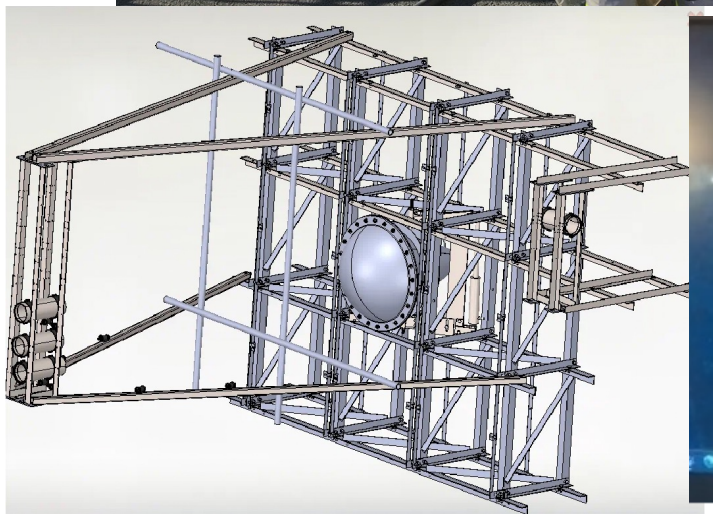
Reinforce rings
• 2.5 mmt, welded

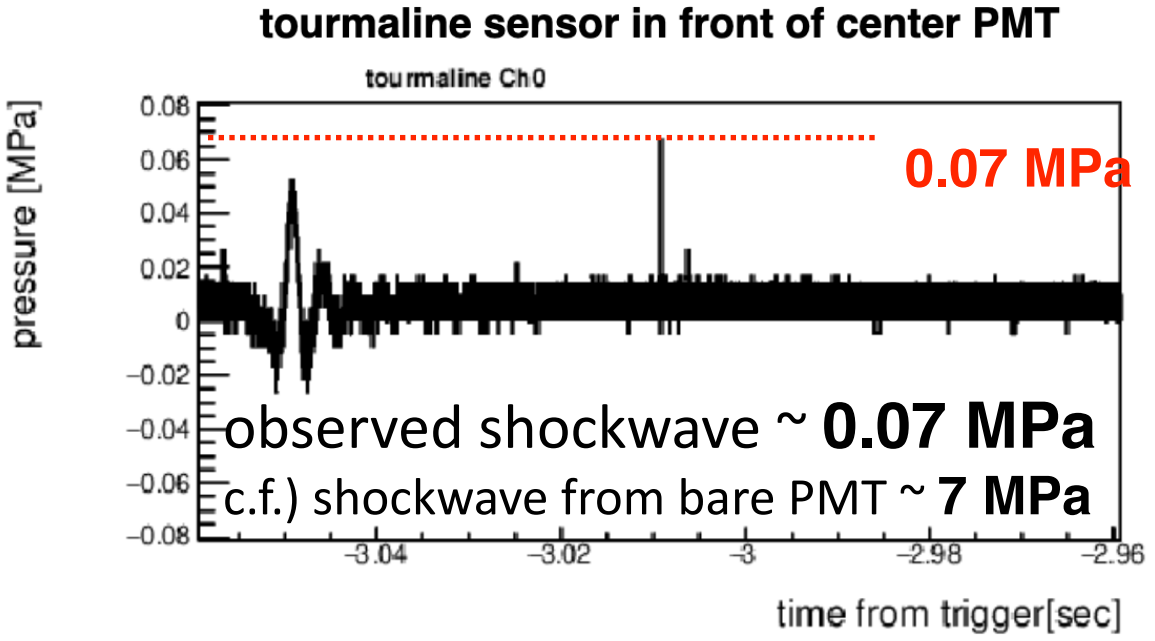
2.4 mmt conical body (SS304L)
by metal spinning

Underwater implosion test of PMT covers

- Test under the deep sea, Spain Majorca
  - Submerge 3×3 PMT frame
  - Crash PMT at 80m depth
- Sensors monitored pressure waves
- Visual taken by high-speed camera

✓ Cover survived after PMT implosion inside
✓ 1/100 shockwave reduction confirmed





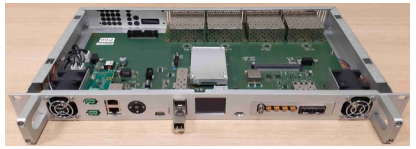
Electronics in HK

- Far detector electronics will be submerged in water
  - Reduction in cable lengths (better signal integrity, less weight)
  - Stringent requirements on reliability (20 years of operation, no serviceability)
  - System to feed nitrogen into vessels (prevent vacuum due to operation in degassed water)
- Modular system
  - High voltage supply (redundant control)
  - Fully redundant low voltage supply
  - Digitizers (T/Q + Time over Threshold) $\sigma_{time} \approx 0.25$ ns, $\sigma_q \approx 0.16$ pC (at 1 PE = 19 pC)
  - Data processing card (clock recovery, buffering, slow control)
- Timing system and DAQ on tank top
- Prototypes complete, performance confirmed, testing pre-production versions
- Starting final production

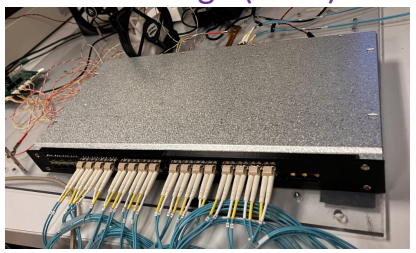
Timing distribution system

- *Two-stage system*
- *GPS/GNSS + atomic clock (redundant)*
- *Achieved clock jitter ≈0.5 ps*
- *Far & near site beam spill timing via GPS/GNSS time stamping*

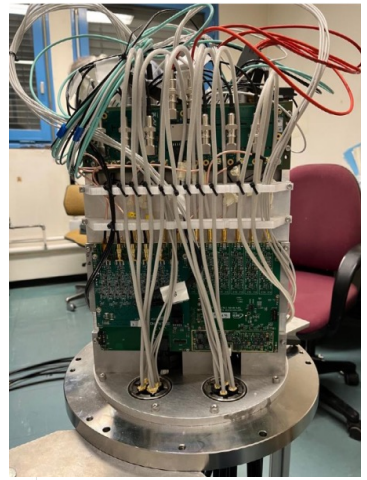
1-st stage distributor

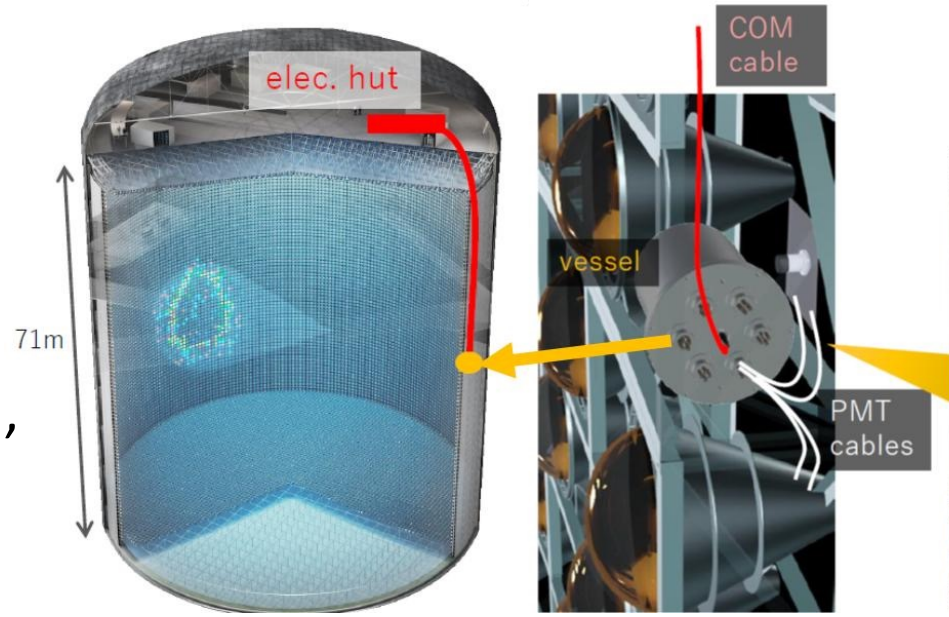


2-nd stage (TDM)

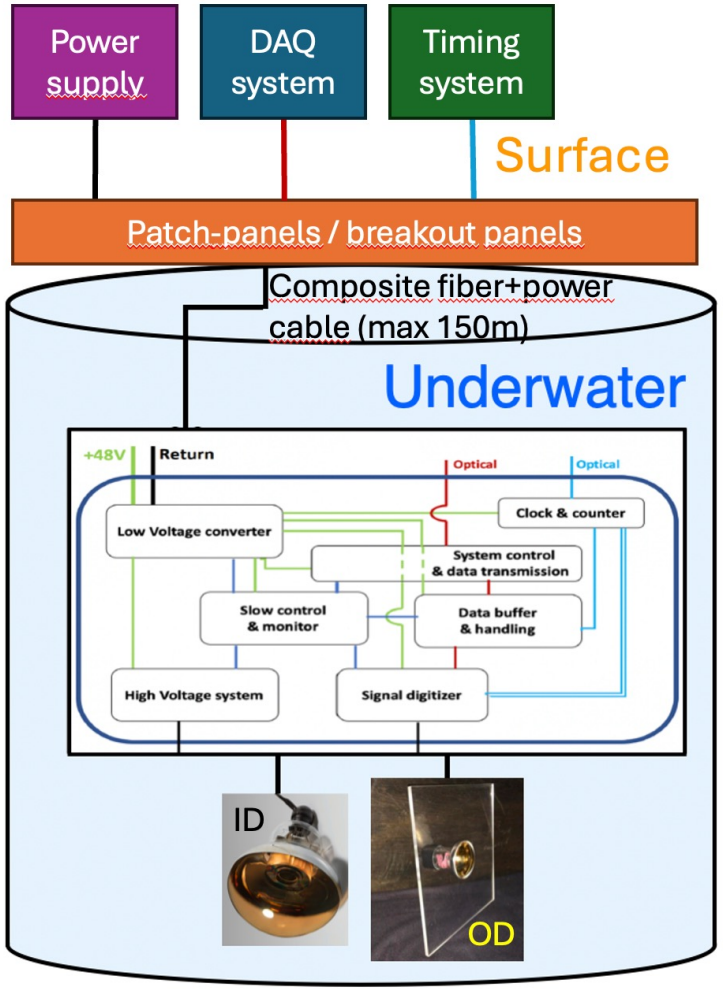


Underwater pressure vessel

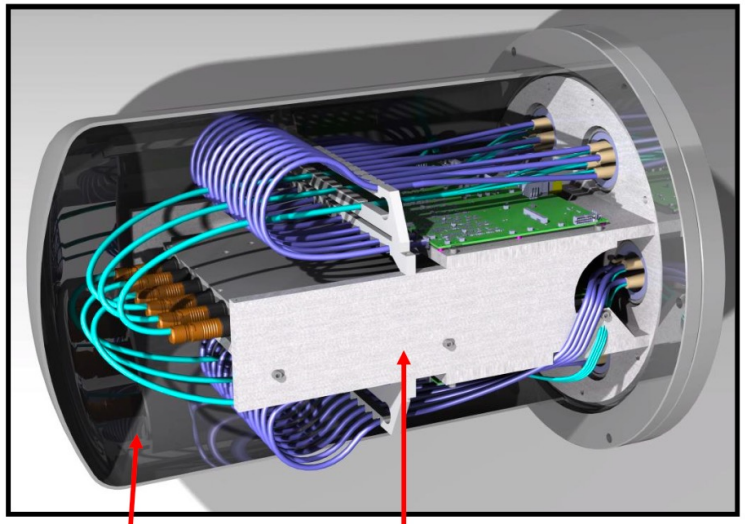


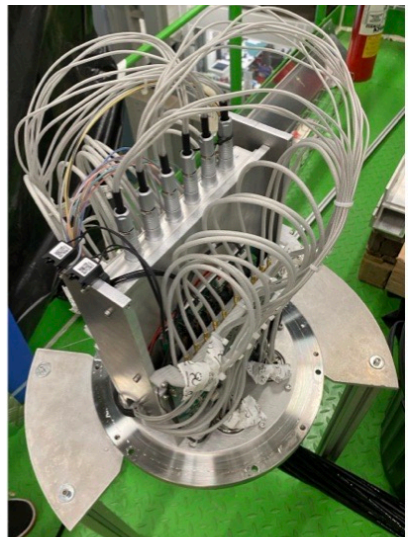


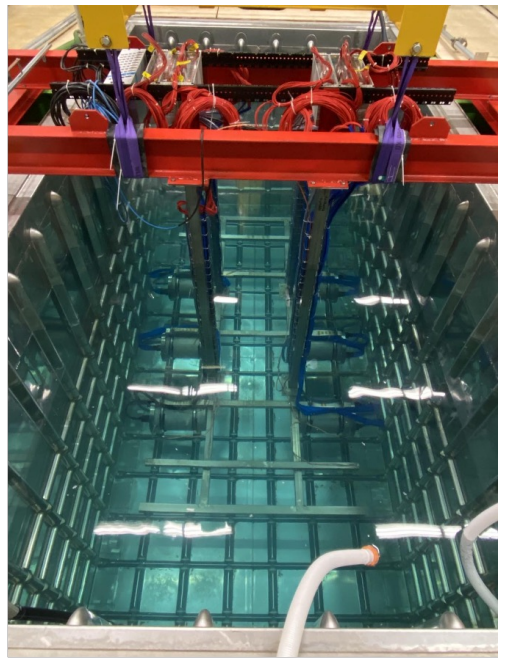
Underwater electronics vessels assembly & test @ CERN NP08



Electronic boards contained in a water-tight vessel at pressures up to 8 bars. (Similar vessel for mPMT electronics ; MCC)





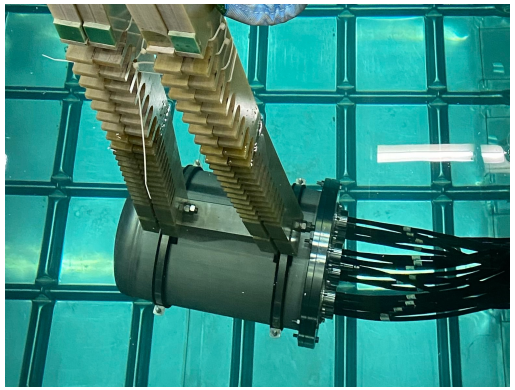


900 underwater electronics units:

✓560 Pure ID: 24x 20’’ PMTs

✓320 Hybrid for both ID+OD detectors: 20x 20’’ PMTs + 12x 3’’ PMTs

Extensively tested in water at CERN and in Japan for several months for stability of humidity, temperature, etc.

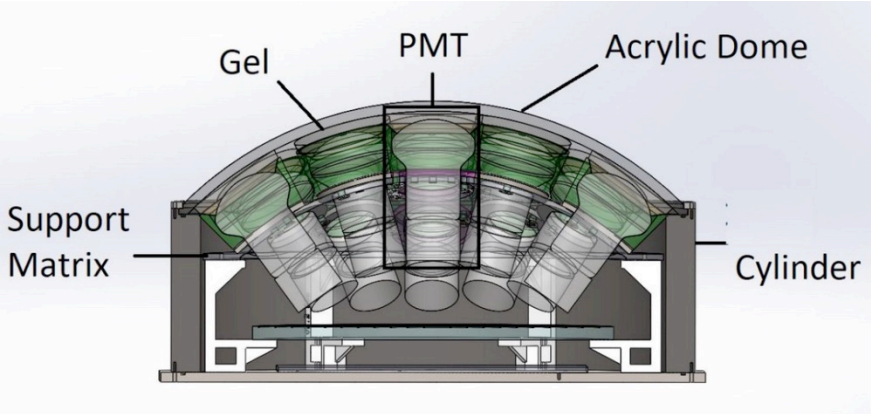


High pressure test in water (10 bar) for every vessel and for a fraction of the assembled units

Gianfranca De Rosa

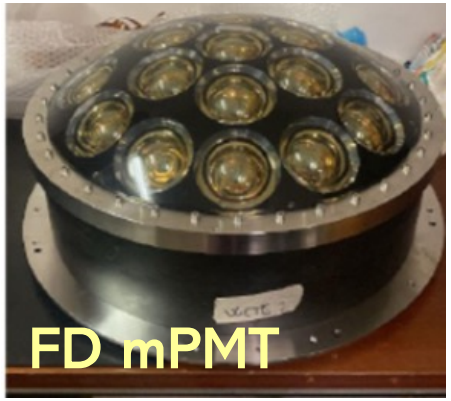
mPMTs in Hyper-K

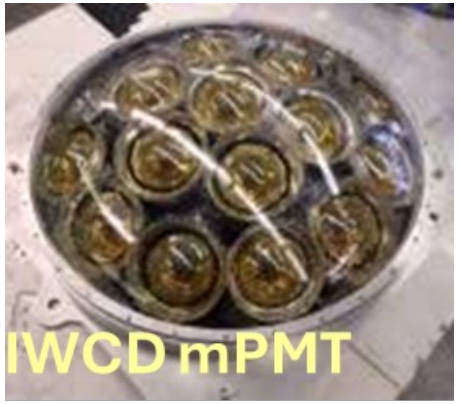
mPMT: 19 3'' PMTs and electronics arranged inside a pressure resistant vessel



808 mPMTs for the Hyper-K FD
- Italy: 300 mPMTs
- Poland: 300 mPMTs
- Canada: 200 LED-mPMT

400 mPMTs for IWCD





LED-mPMT: 5 PMTs replaced with LED

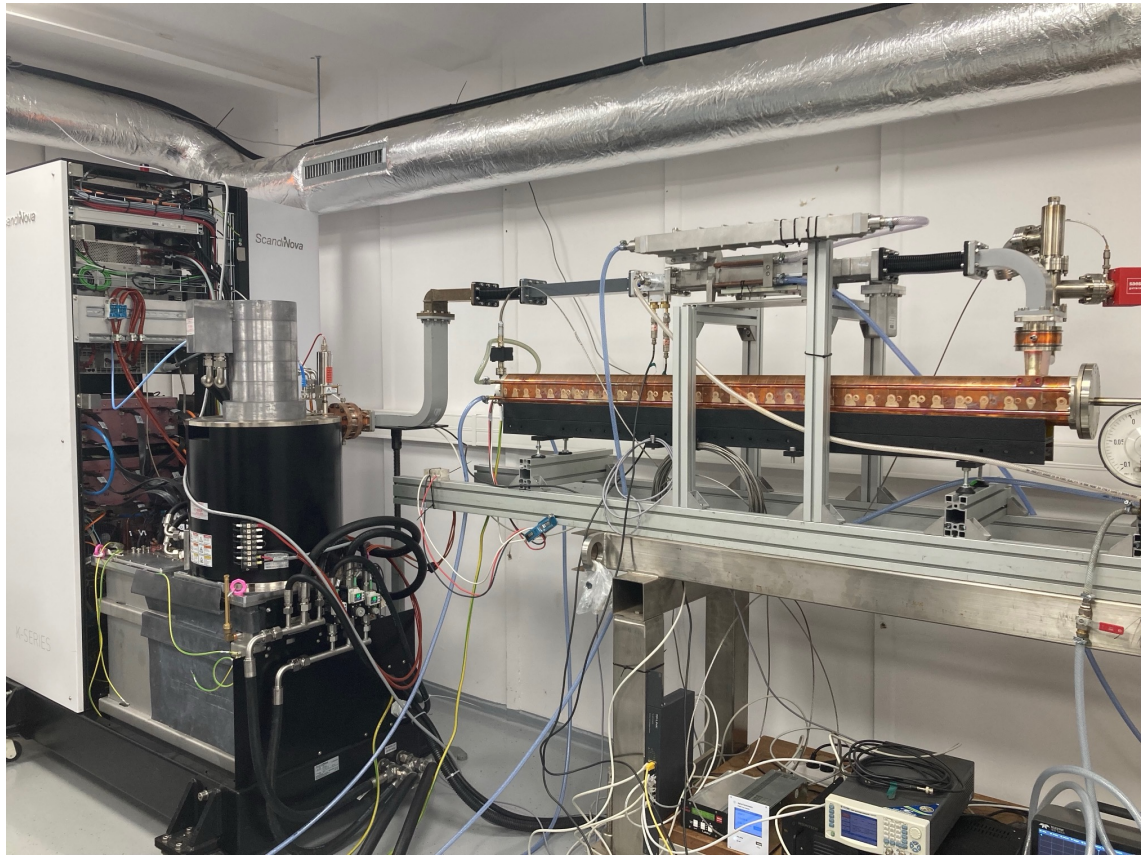
Common R&D but :

FD mPMT different from IWCD mPMT:
- Withstand pressure → robust backplate, POM-C cylinder
- Low radioactive contamination
- Different (slower, low power) electronics

LED-mPMT
- Mechanics: same as FD mPMT except for PMT support
- Electronics: same as FD mPMT

Other instrumentation highlights ; LINAC / OD

Providing precise absolute energy calibration in 3-24 MeV
(5-16 MeV @ Super-K LINAC)

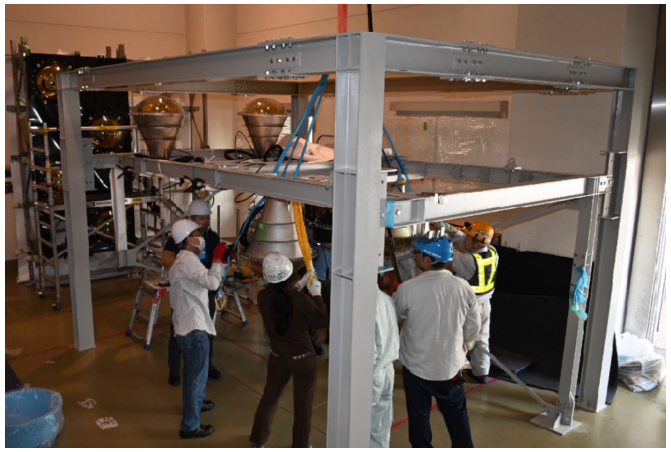


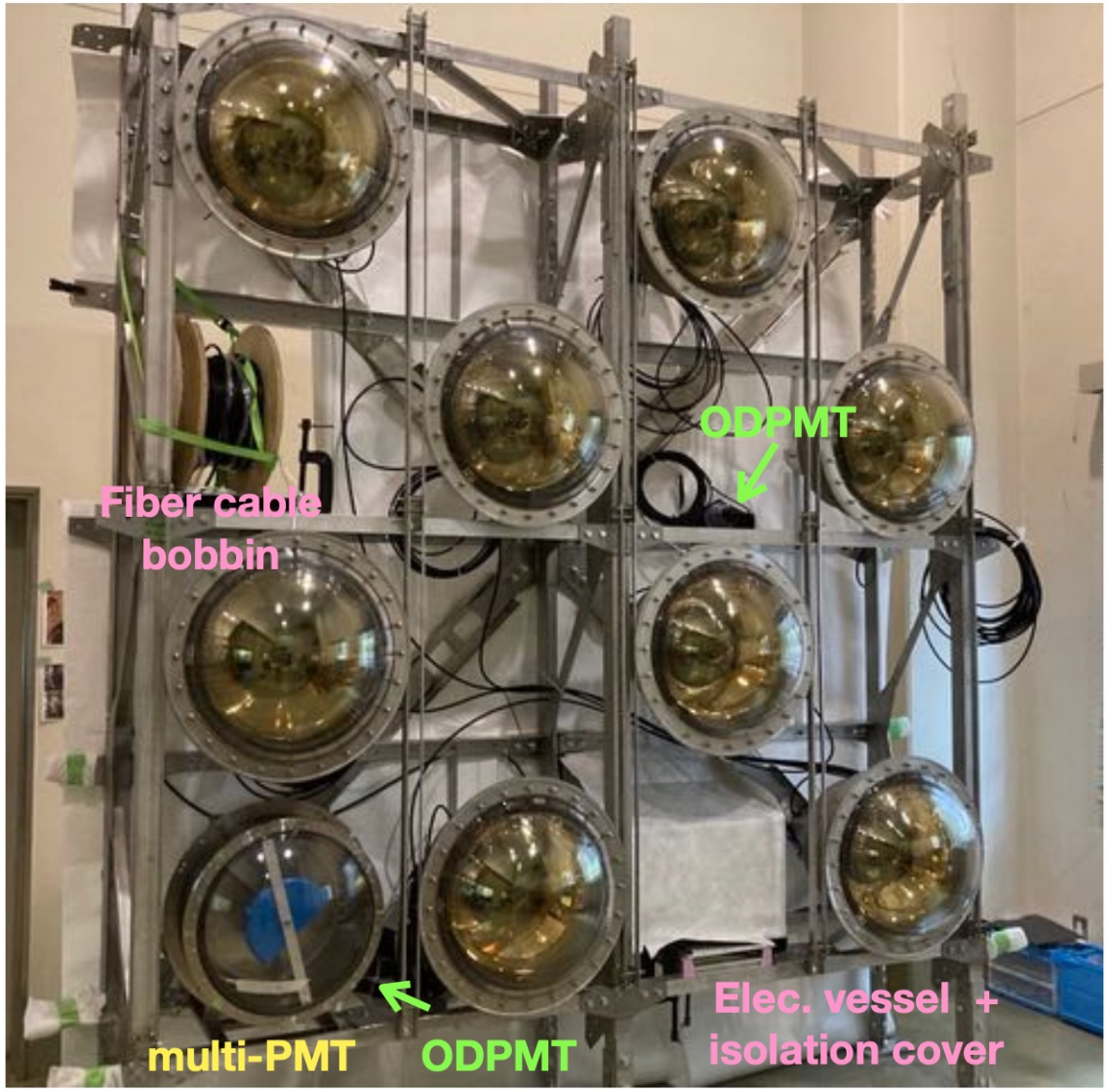
@NCBJ 16 Sep 2025

Hyper-K OD : 1-m OD layer w/ 3” PMT + WLB
(Super-K OD: 2-m OD layer w/ 8” PMT + WLB)

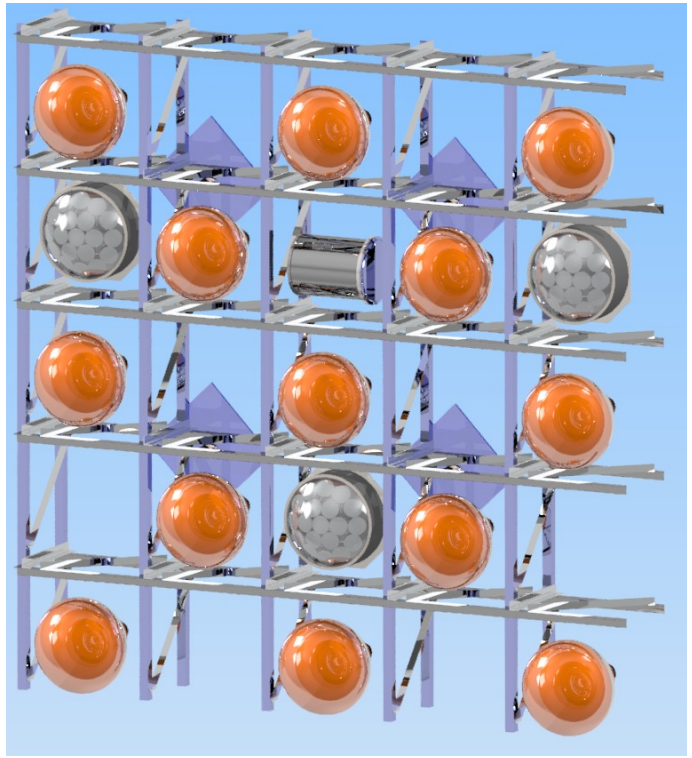
Hyper-K PMT/Electronics installation

Mockup test (May 2024)

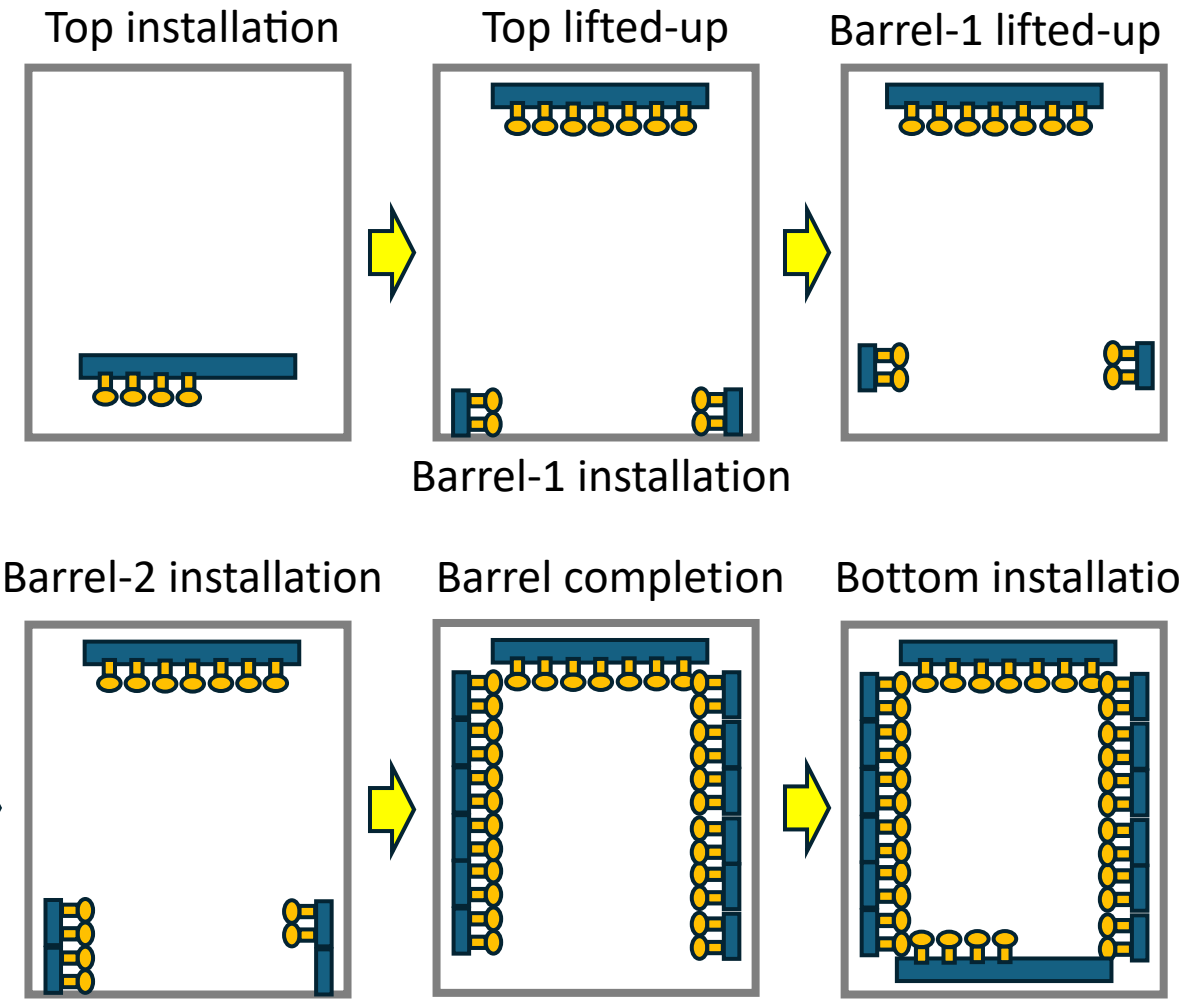




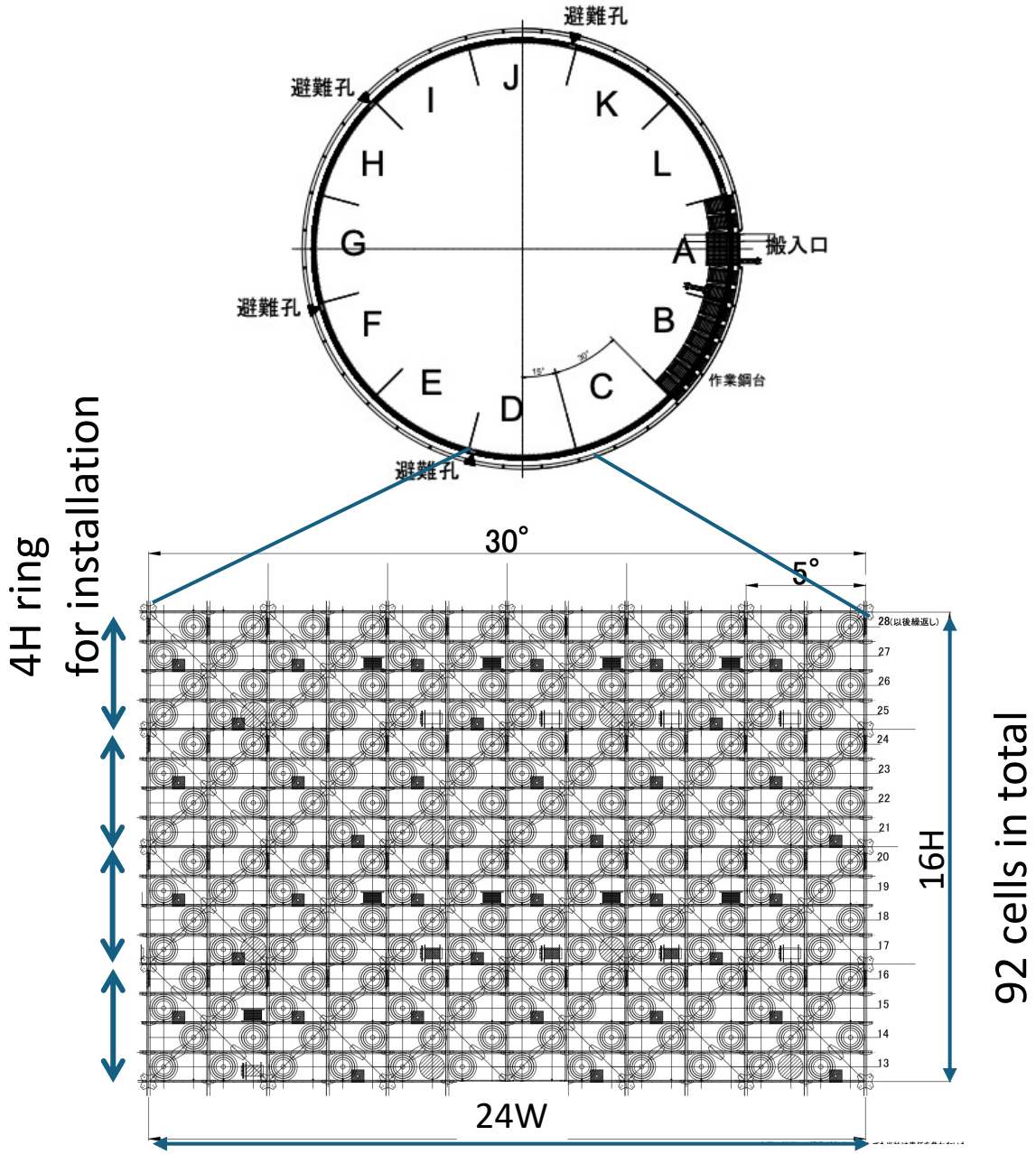
	Top + Bottom	Barrel
ID 20” PMT	6456	13,248
mPMT	256	552
OD 3”PMT	1,076	2,484
Elec. Vessels	290	594
MCC (MPMT)	72	32



Hyper-K FD PMT installation

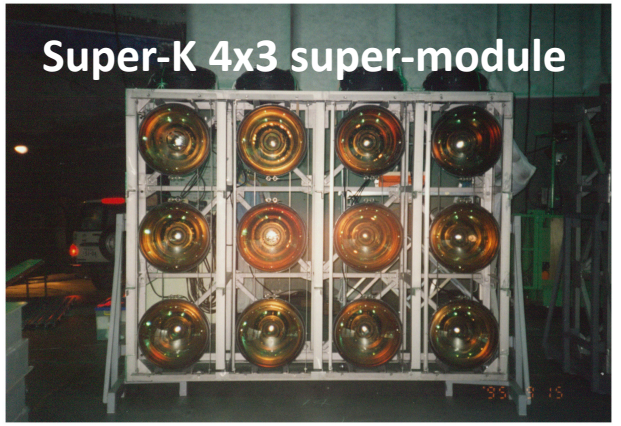


576 20”IDs + 108 3”ODs + 24 mPMTs + 29 vessels / 4H ring

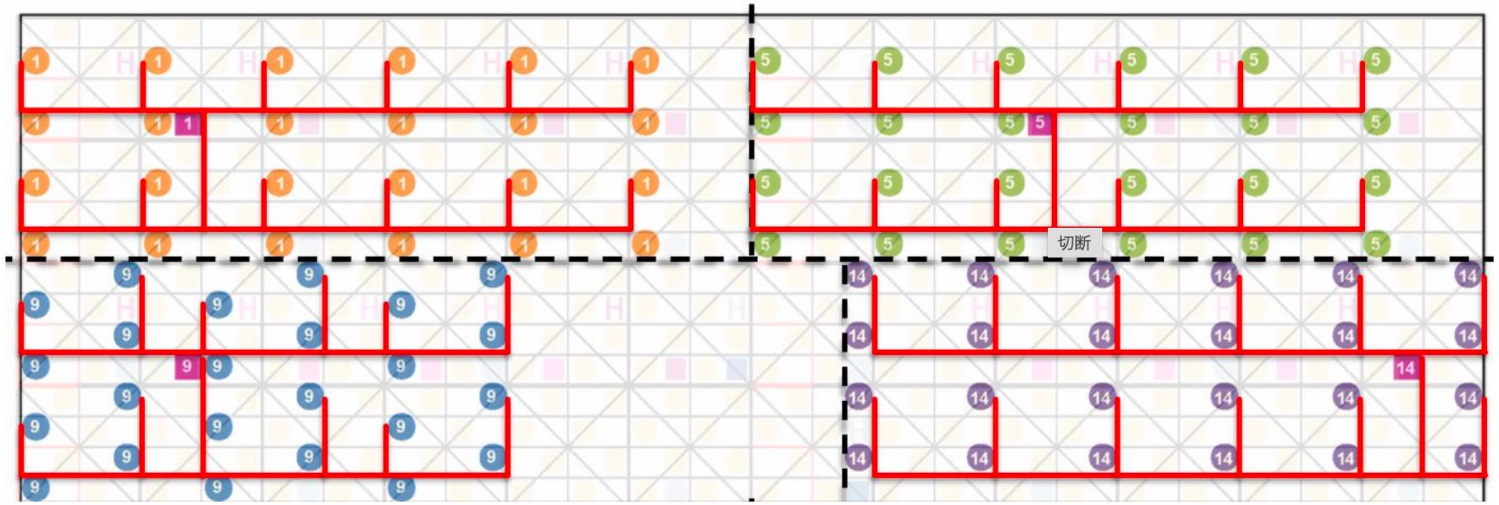


Super-K 1st construction/ barrel installation (1995)

- 17 3x4-super modules stacked in a vertical tower, and lifted up
- One tower/day
- repeat 38 days → Complete.



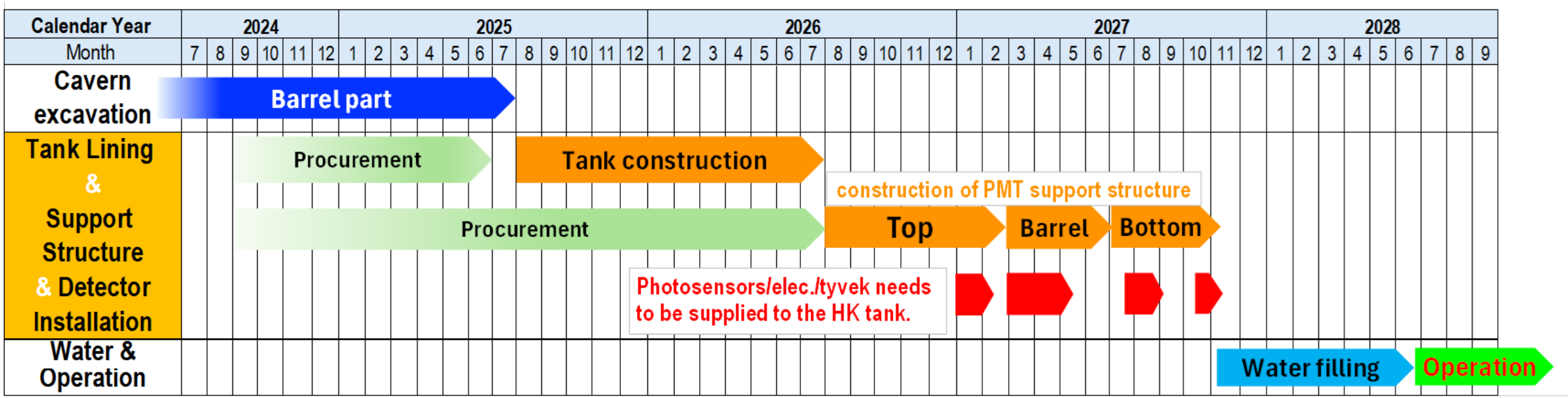
For Hyper-K, a ring of 4x288 columns installed in 3-days, because of “interleaving” of cabling



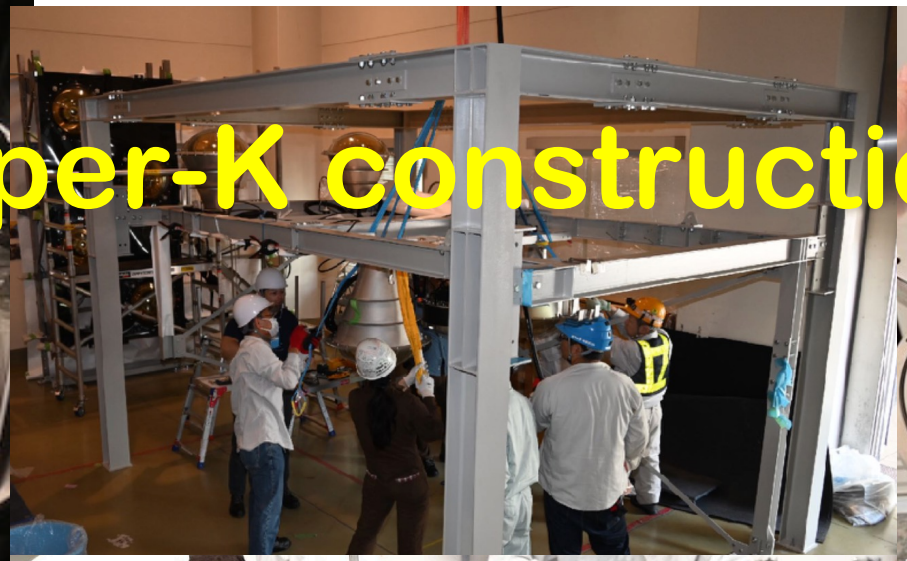
- 1 electronics vessel failure → 24 dead channels
- Prevent concentration of dead channels

HK FD construction timeline

- June 2025: Cavern construction completed.
- August 2025 - July 2026: Tank lining construction.
- Jan 2027: Top, Mar-June 2027: Barrel, July-Oct 2027 Bottom installation.
- Nov 2027-June 2028: Water filling → June 2028 Operation starts !



Now Ready for Hyper-K construction !



Summary

- Hyper-K is based on 45yrs legacy of underground water Cherenkov technology.
  - Scale-up by x2 of Super-K in a dimension for 1-order larger FV.
- Not a simple scale-up, while new technical challenges in instrumentation.
  - Cavern : "World-largest" span. Information-oriented design and excavation.
  - New 50cm-PMT: double the PDE, pressure tolerance, and resolution.
  - New PMT covers:
  - mPMT : 19 of 3" PMTs based on KM3Net legacy. Photon direction information.
  - Underwarter electronics: Reduction of PMT cables. Long term stability and lifetime. Underwater vessel and feed-through against the pressure.
  - Detector Integration: One-year installation of 20K 50cmPMTs and multiple components.
- Installation work will start in one-year. Operation foreseen in 3 years.

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