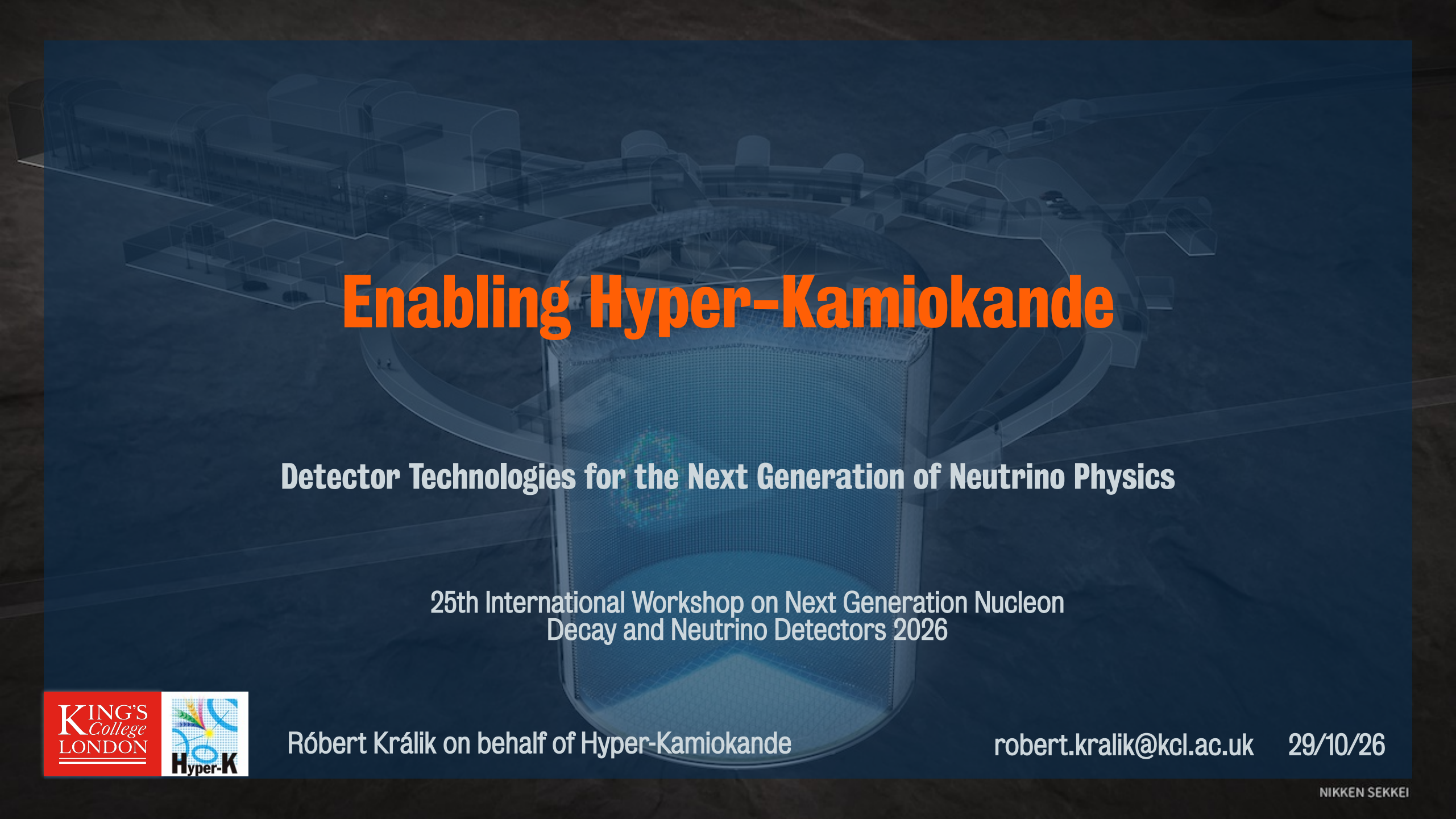


Enabling Hyper-Kamiokande

Detector Technologies for the Next Generation of Neutrino Physics

25th International Workshop on Next Generation Nucleon Decay and Neutrino Detectors 2026

KING'S College LONDON

Hyper-K

Róbert Králik on behalf of Hyper-Kamiokande

robert.kralik@kcl.ac.uk

29/10/26

NIKKEN SEKKEI

The Hyper-Kamiokande experiment



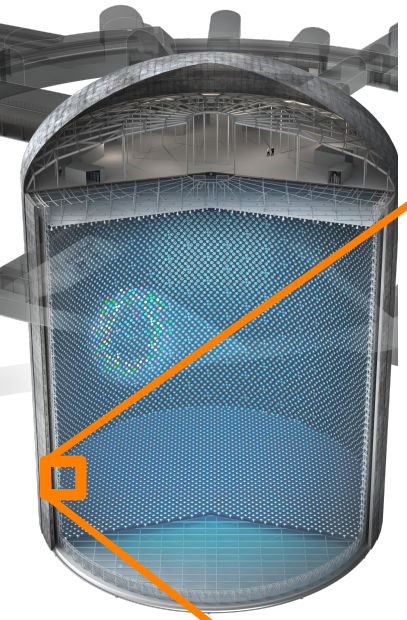
Two new water Cherenkov detectors

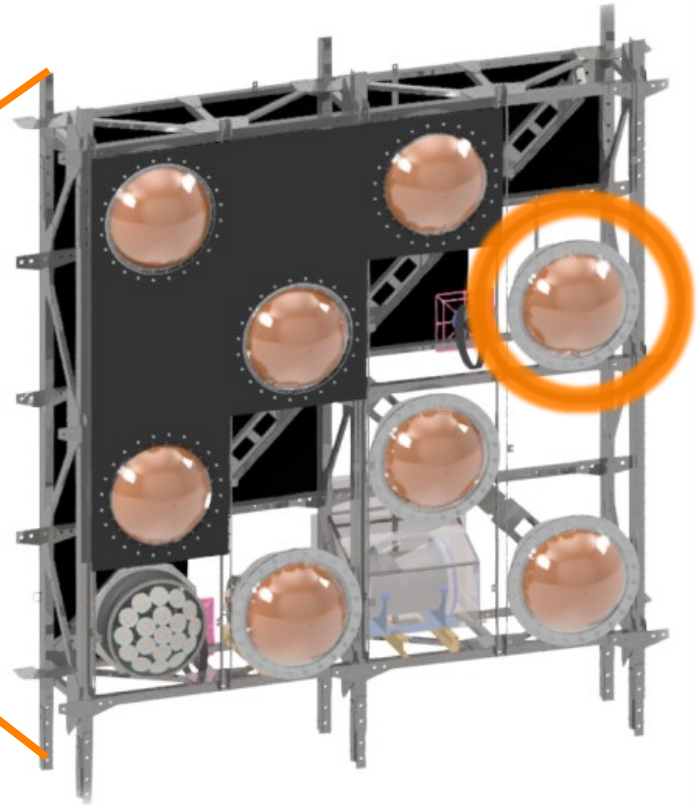
Separated into inner and outer detector

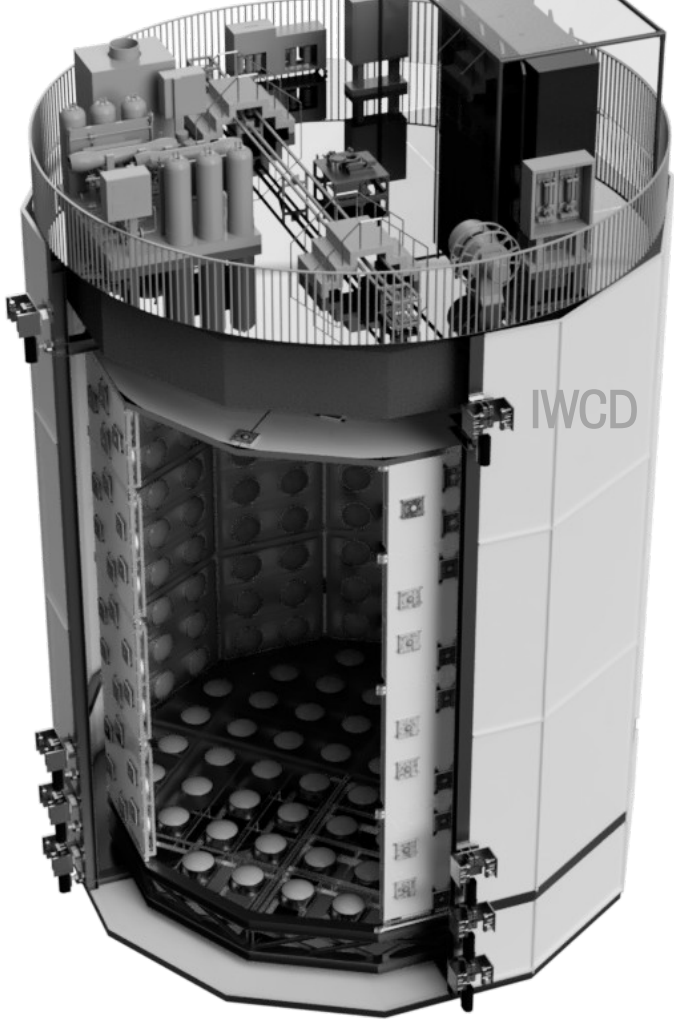
Better light detection. Lower backgrounds. Greater physics reach.

See talk on "*Latest Status and prospects of Hyper-Kamiokande*" by Christophe Bronner for more details

Inner Detector photosensors





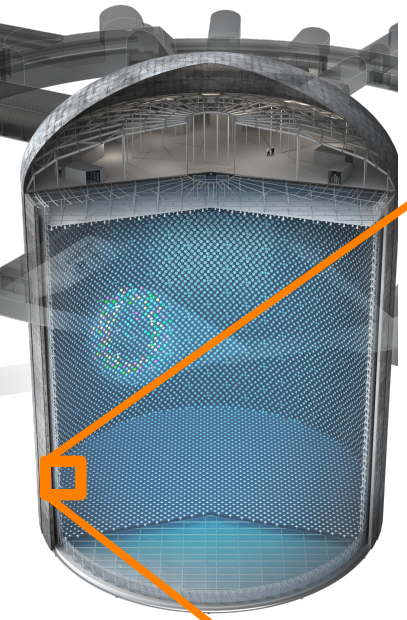


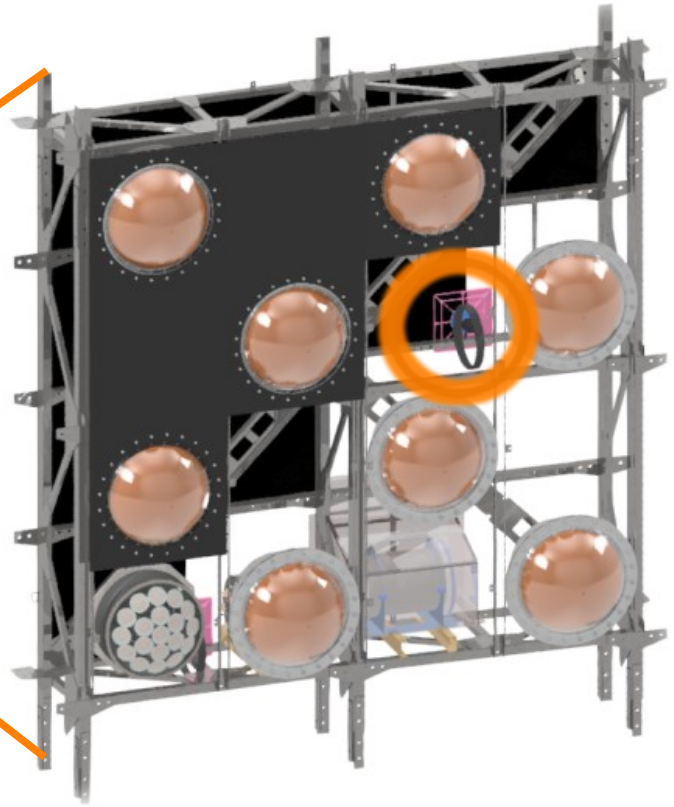


20,000 upgraded 20” PMTs

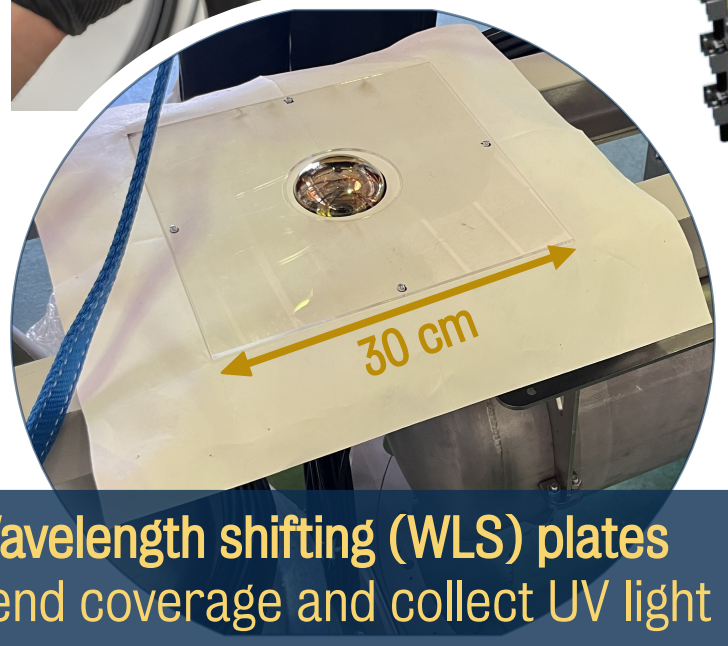
- 20% photocoverage

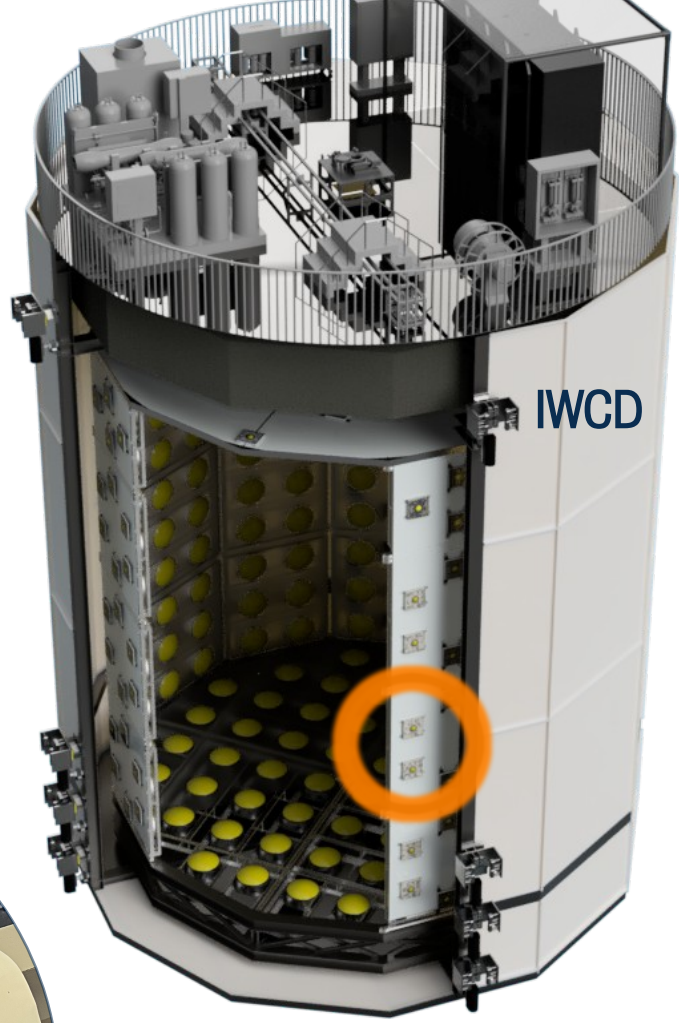
Outer Detector photosensors









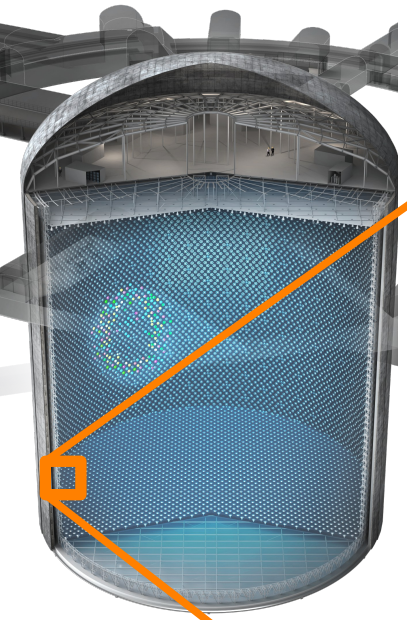


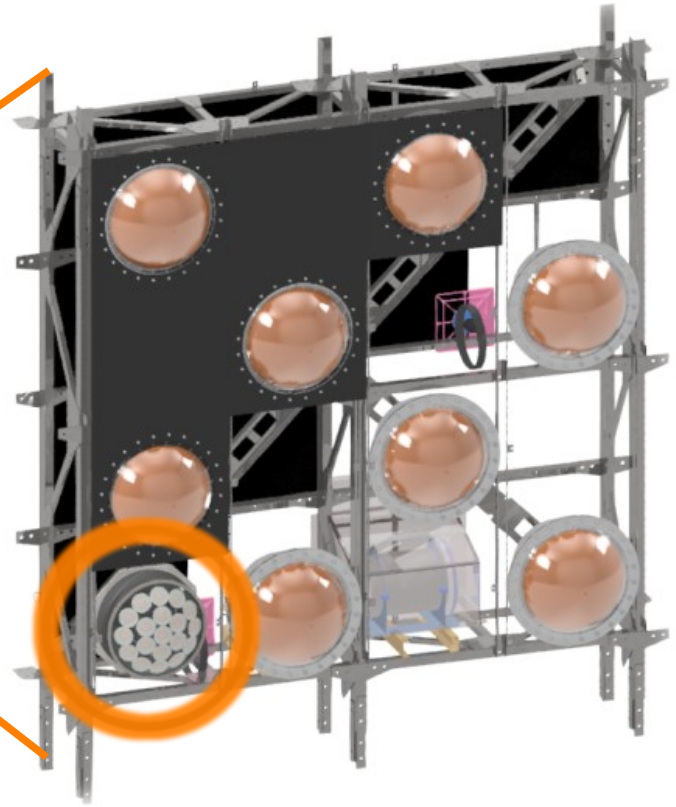
~4,000 Outer Detector units

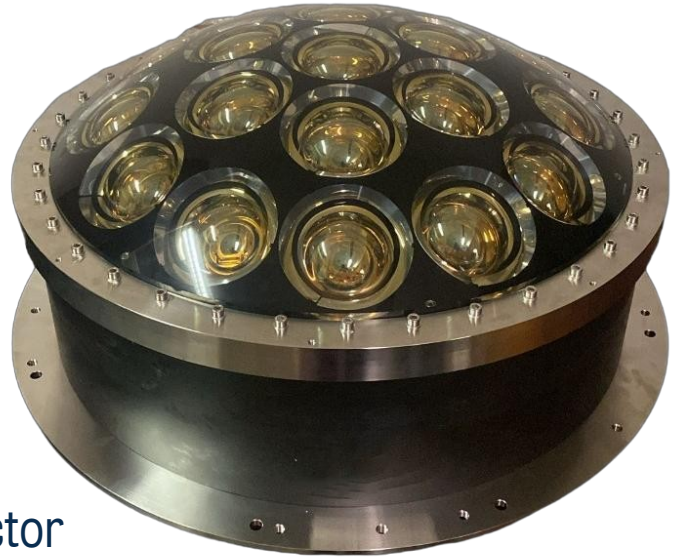
- Each unit: 3” PMT + 30×30 cm WLS plate
- 3,560 in the Far Detector, 368 in the IWCD

Wavelength shifting (WLS) plates
Extend coverage and collect UV light

Multi-PMT (mPMT) modules









~1,200 multi-PMTs

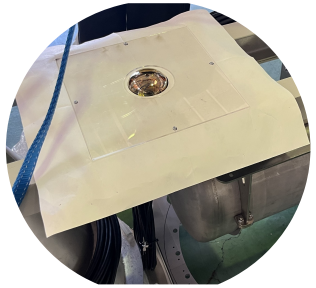
- 808 high-pressure low-noise modules in the Far Detector
- 400 high-rate low-pressure modules in IWCD

Current status of Hyper-K photosensors

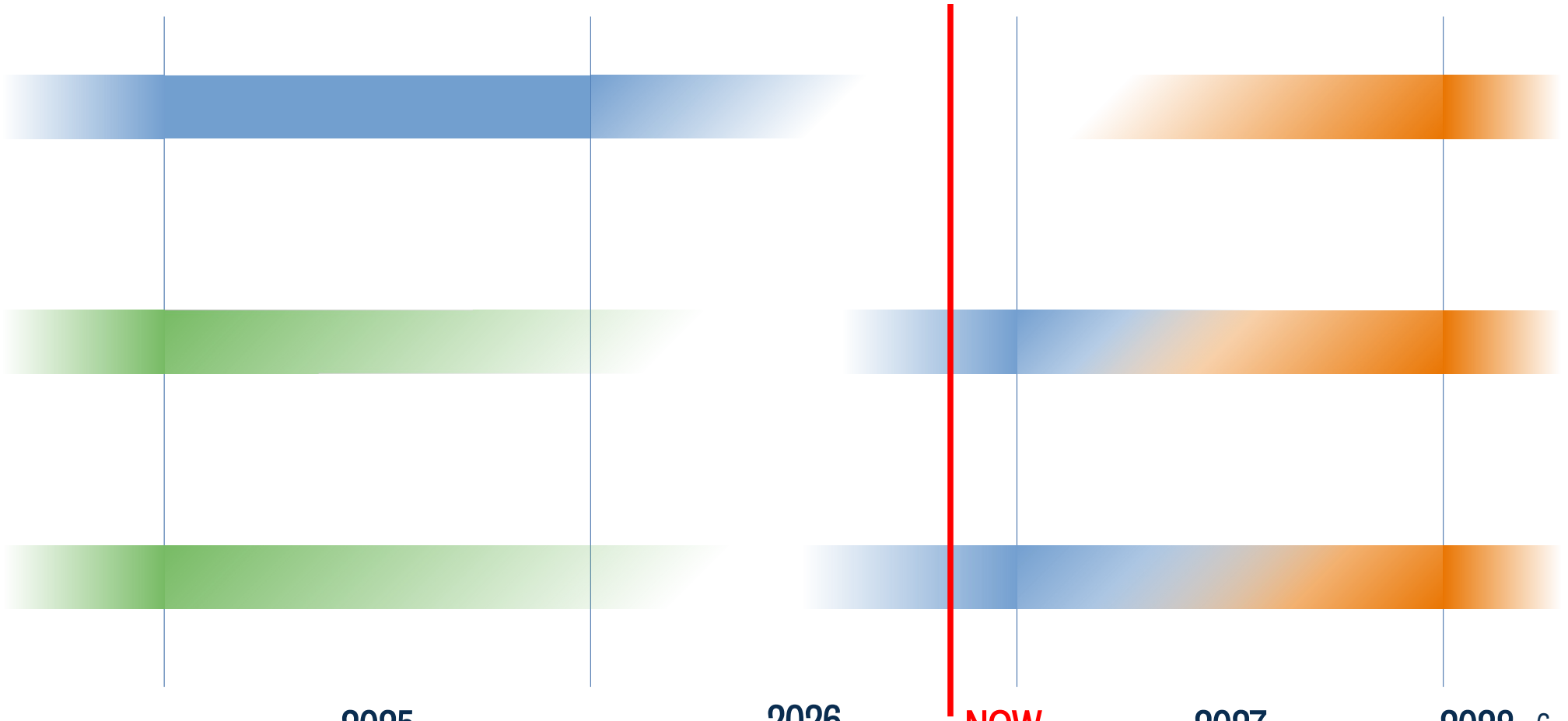
20” PMT delivery and testing completed

Outer Detector unit and multi-PMT delivery, testing and assembly now underway





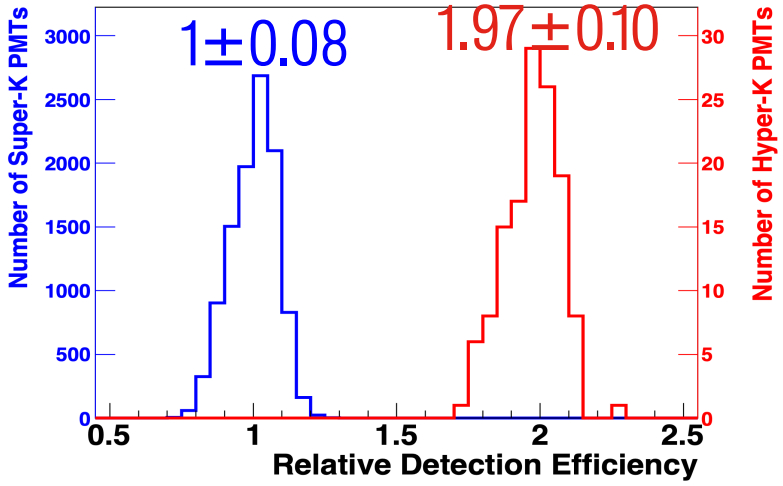


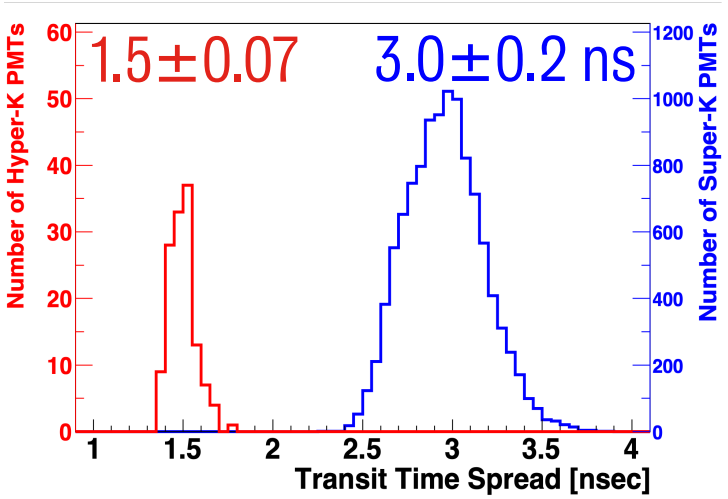


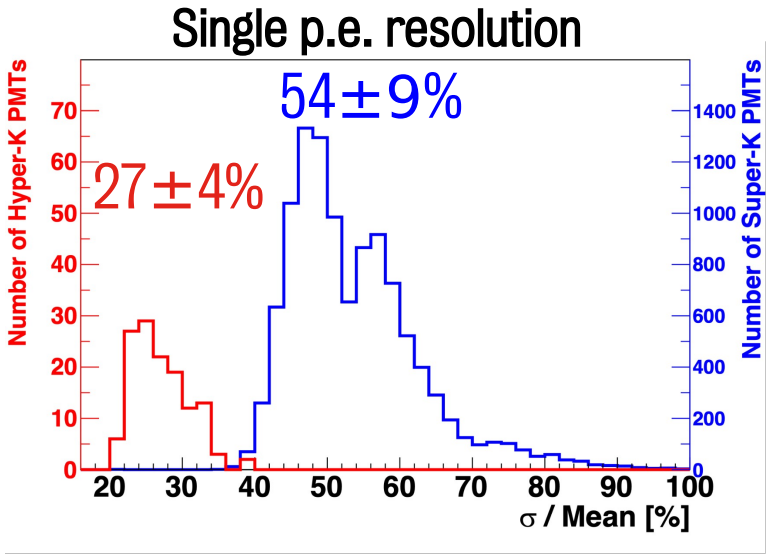
Upgraded 20” PMTs – design

2× single-photoelectron detection efficiency, timing & charge resolution, pressure tolerance

136 Hyper-K 20” PMTs were installed in Super-K in 2018 – demonstrating improved performance







Further tests performed on a subset of PMTs – finished Summar 2026

- Small number of PMTs showed instabilities, minimum failed requirements

See poster on “High statistics measurement of the performance of the Hyper-Kamiokande 50cm PMT ” by Christophe Bronner for more details

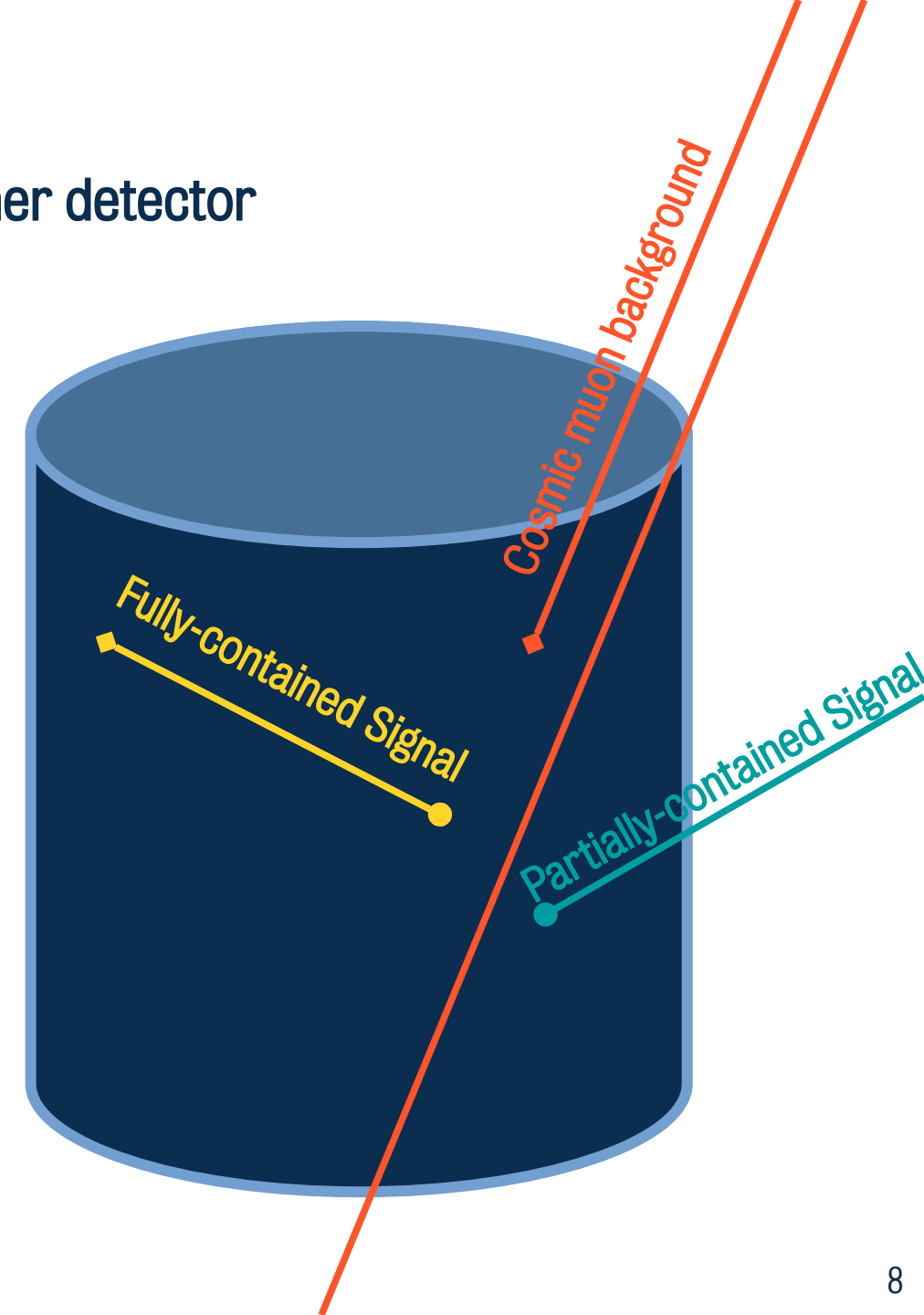
Outer Detector

Identify and reconstruct particles entering and exiting the inner detector

Cosmic muon rate at Hyper-K

~45 Hz

~4,000,000 cosmic muons / day
15× the Super-K rate



Veto cosmic muons with high efficiency: >99.999%

- 1 in 100,000 missed muons (10^{-5} inefficiency)

Help identify and reconstruct signal and background

Reconstruct cosmic muons to reduce spallation background

Outer Detector PMT design and requirements

Low dark rate

< 2 kHz

At 25°C, ≥3 days of darkness
~600 Hz at Hyper-K

Reduces accidental hits and false vetoes (false positives)

Single-PE sensitivity

QE >10%

Average over 300-500 nm

Peak-to-valley ratio > 2

Reduces false negatives - most hits have low signal

Charge and Timing

Charge < 70%

Time < 3 ns

Supports event and track reconstruction

Smaller size than in Super-K: 8” → 3”

- Better tolerance to high pressure and magnetic field effects
- Lower dark noise and better timing

Selected the 3” Hamamatsu R14374 in the beginning of 2026

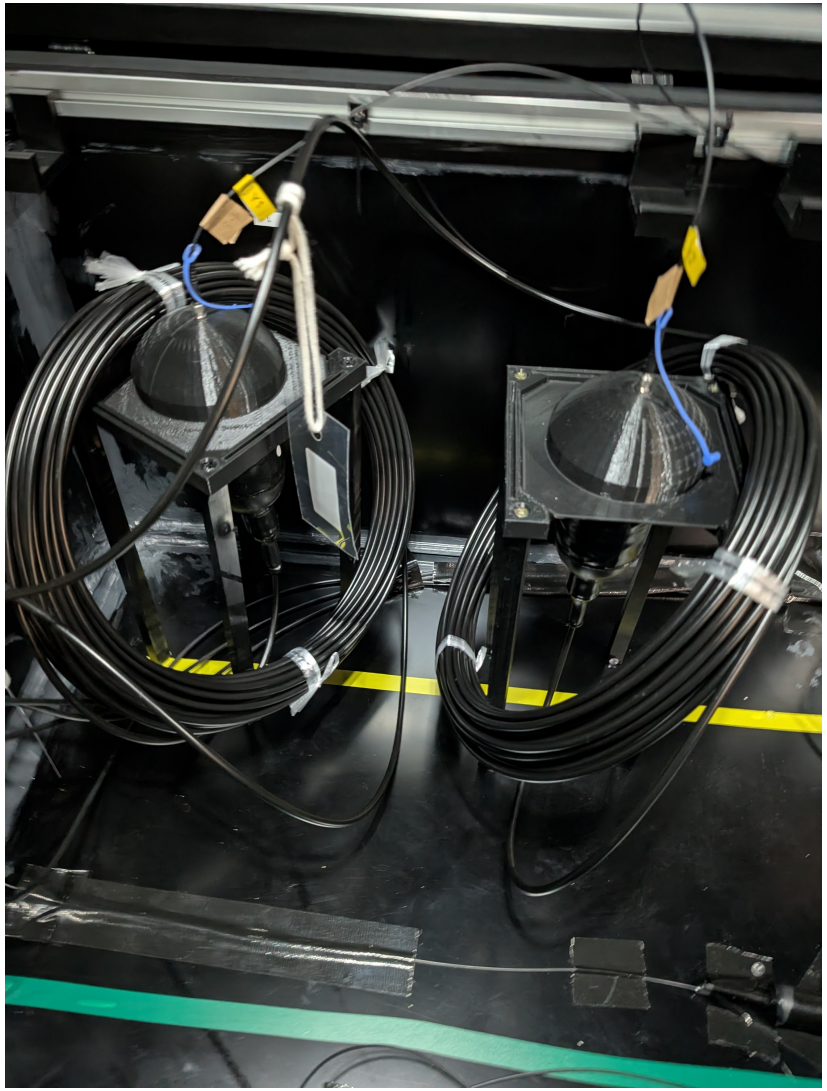
Outer Detector PMT testing at the University of Toyama

Delivery of Hamamatsu PMTs from Summer 2026

Every PMT is tested before integration into an OD unit

- Dark rate, single p.e. charge resolution, peak-to-valley ratio
- ~16% PMTs tested so far
- All tested PMTs meet the acceptance criteria



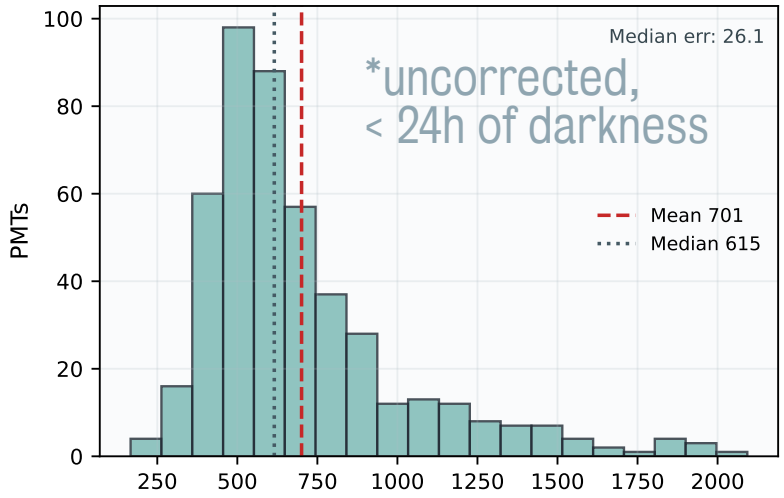


Outer Detector PMTs – Measurements results

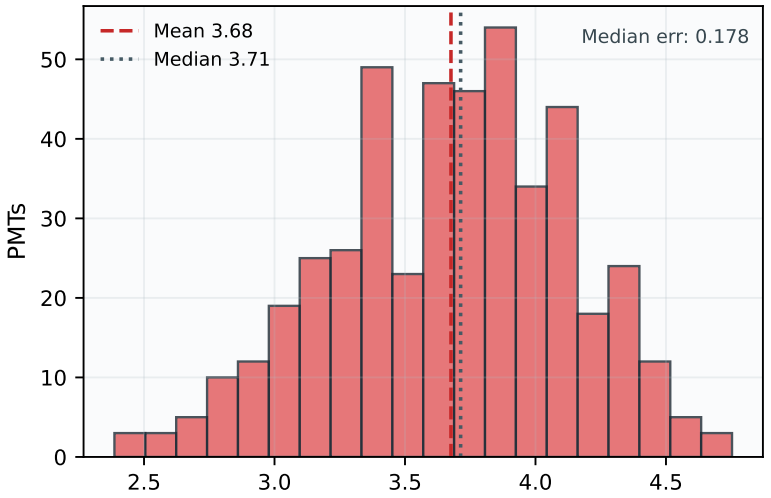
Good agreement between our measurements and Hamamatsu

- Hamamatsu reports dark rate 150 – 500 Hz
- Measured parameters for all PMTs within requirements
- Hamamatsu reports time resolution of ~1.3 ns and good QE
- Detection-efficiency measurements on pre-production PMTs confirm Hamamatsu's results

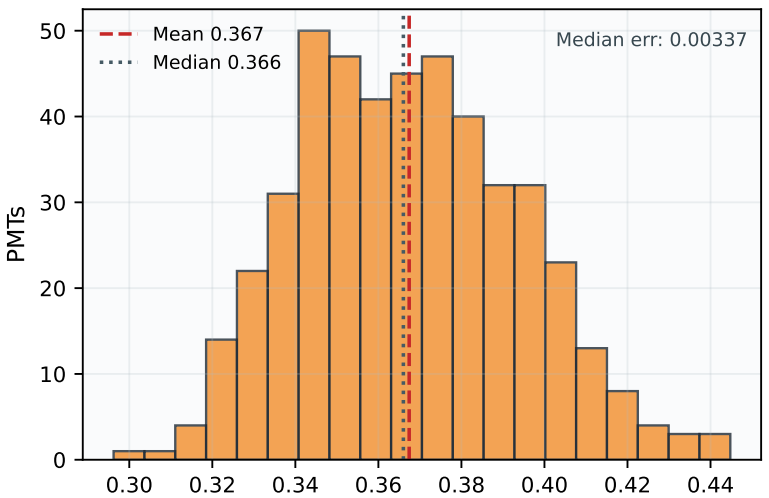
Requirement < 2 kHz



Requirement > 2



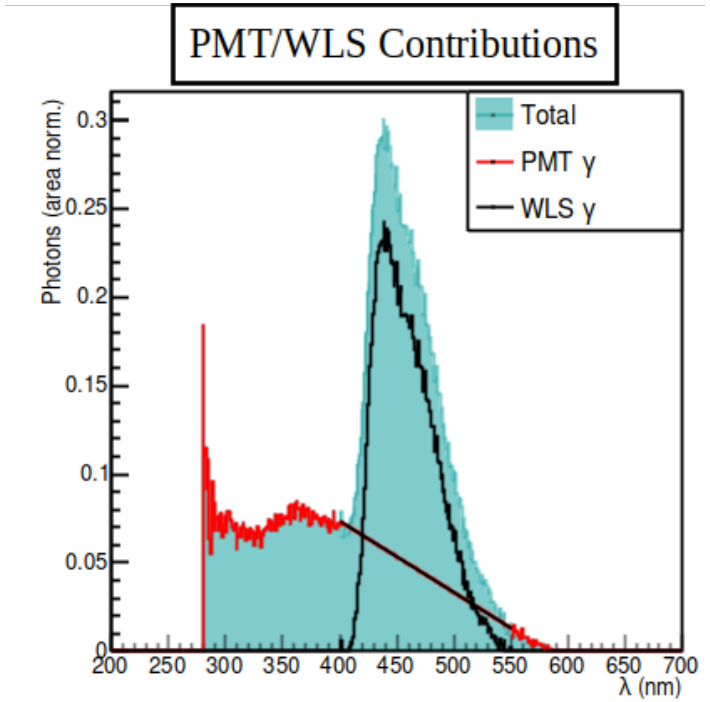
Requirement < 50%

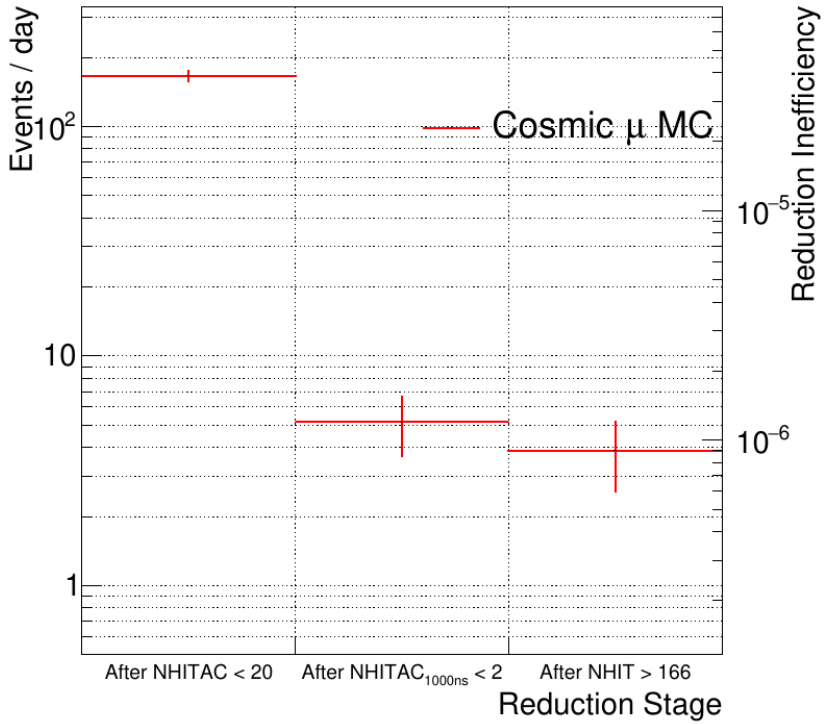


Outer Detector WLS plates and performance

Wavelength shifting (WLS) plates increase light collection > 2×

- PMMA plastic with 50 mg/L of POPOP fluorescent dye
- Shift UV Cherenkov light to ~410 nm
- ~3000/4000 plates produced, ~1600 delivered





Simulations with current setup show inefficiency of cosmic muon tagging ~10^{-6}

- Better than the required inefficiency of 10^{-5}
- ~3.8 residual cosmic muons per day, compared with ~80 atmospheric-neutrino signal events per day
- After 1 m fiducial cuts, inefficiency can reach ~10^{-9}

R. Shinoda, Outer Detector of Hyper-Kamiokande, arXiv:2605.11580

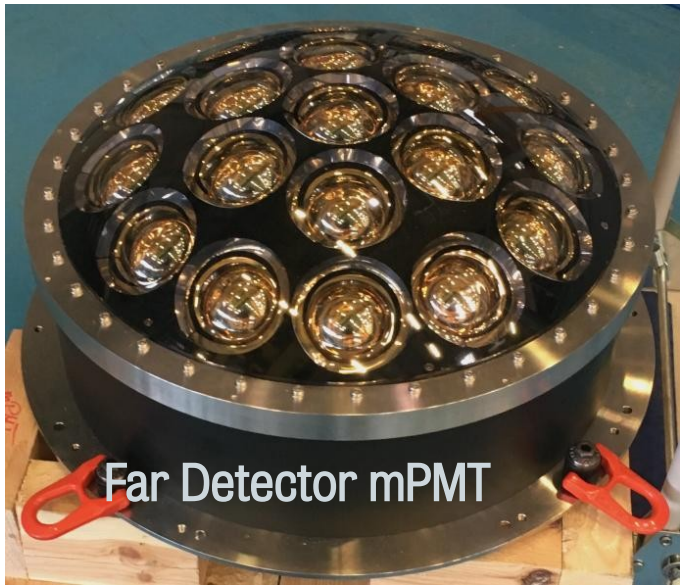
Multi-PMT design

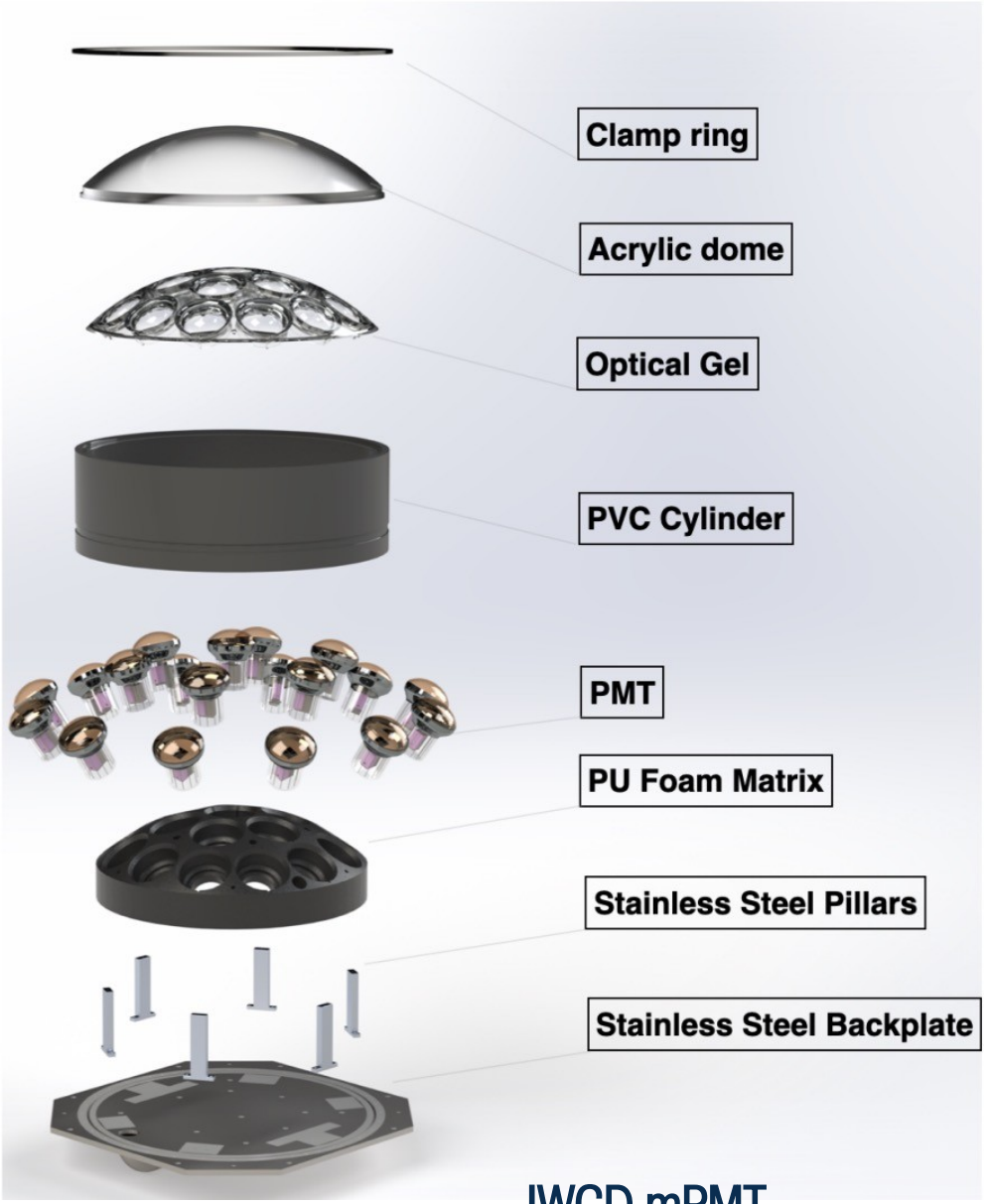
19 3” PMTs and electronics housed inside a pressure resistant vessel

Optical gel couples the PMTs to a transparent acrylic dome

Anodised aluminium reflectors increase the effective light-collection area of the PMTs

808 multi-PMTs (mPMTs) installed in the Far Detector and ~360 in the IWCD





IWCD mPMT

Benefits of multi-PMTs

Intrinsic directional sensitivity
&
improved angular acceptance

Smaller PMTs result it
- Better timing resolution (TTS_{FWHM} ~1.3 ns)
- Lower magnetic field sensitivity and dark counts
  - Further reduced by considering local coincidences

Photon detection
- High granularity and photon-counting capability
- Dynamic range up to 100 p.e. per module



Increased redundancy
- Failure of single PMT doesn't compromise entire position

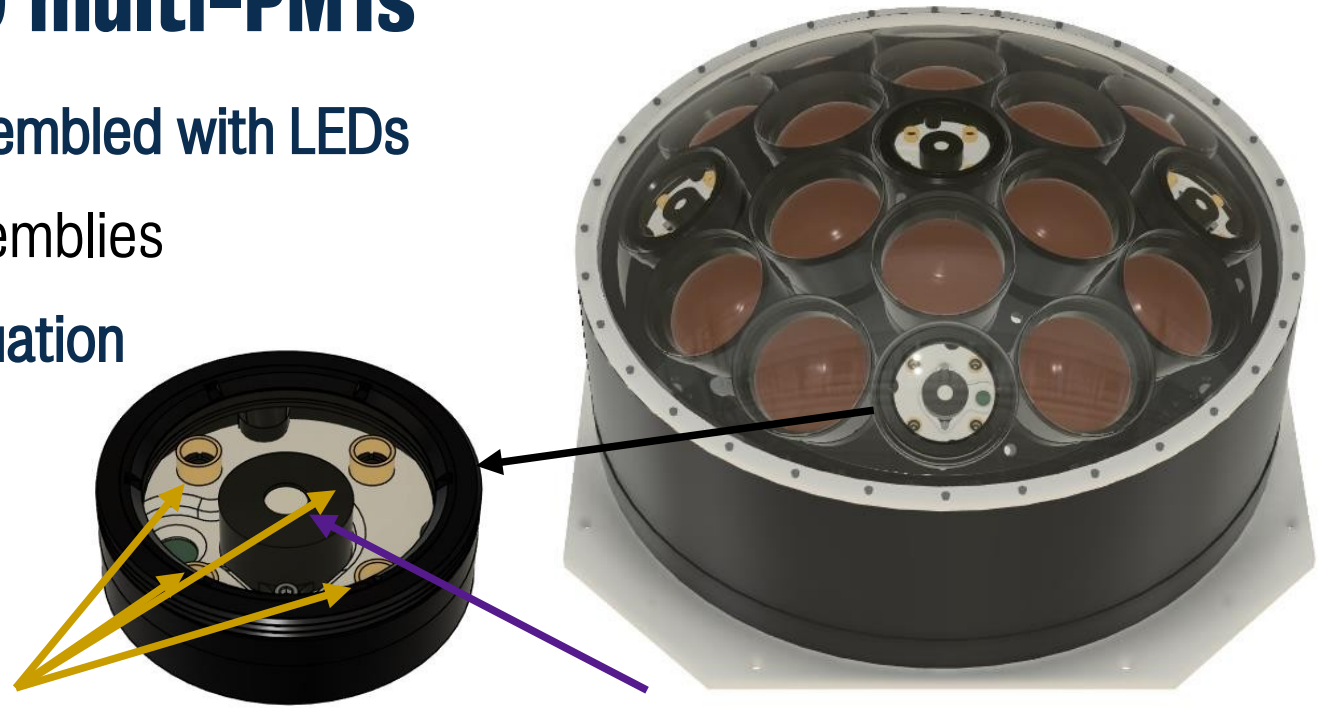
Results in improved reconstruction
- Better vertex and angular resolution, especially for low energies
- Vertex reconstruction near detector walls also for high energies
- Especially important for smaller IWCD

LED multi-PMTs

Quarter of Far Detector mPMTs will be assembled with LEDs

- 5 small PMTs will be replaced by LED assemblies

Fundamental for calibration of water attenuation



4 Collimators
Monitor water attenuation and local impurities (like bacteria)

1 Diffuser
Calibrate angular response and timing of 20” PMTs



The IWCD mPMTs will have embedded LEDs:

- 6 slow LEDs with diffusers for photogrammetry
- 3 fast LEDs with diffusers and collimators for single PE response and timing calibration

Multi-PMTs Production and Status

Full production began in 2026 – scheduled to finish in 2027

Rigorous testing of all components

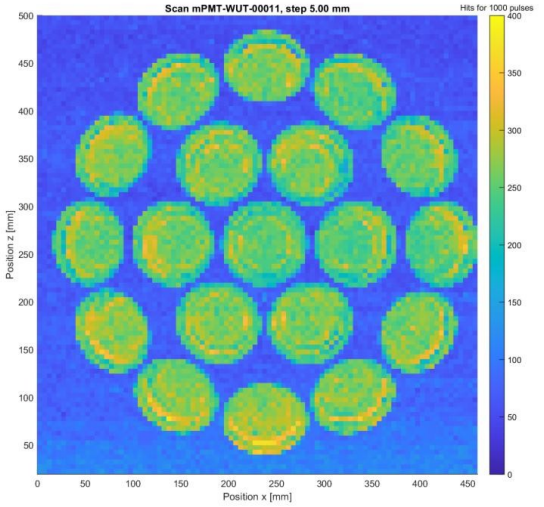
- Tests of small PMT assemblies (PMT+HV+Front End) fully ramped up
  - Check gain, dark count, communication, and power supply
  - So far tested about a third of all assemblies
  - ~0.8% failure rate

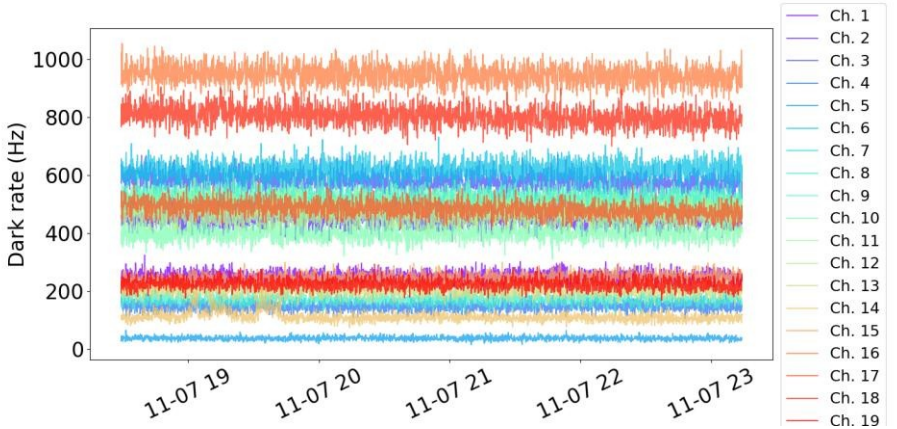
Assembly into full mPMT units ongoing

Fully assembled mPMT units tested in dark box

A subset of units tested with a picosecond laser





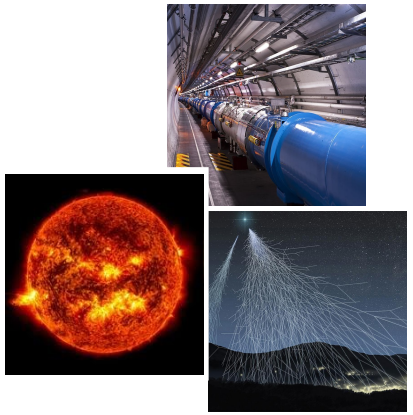


A. Rychter, The design and performance of multi-PMT modules for the Hyper-Kamiokande experiment, DOI: 10.1016/j.nima.2026.171331

Demonstration of Multi-PMTs in the Water Cherenkov Test Experiment* proved their readiness

*Not part of Hyper-Kamiokande

Conclusions



Precise photon detection and background rejection are essential to achieving Hyper-K's ambitious physics goals



ID PMT delivery and testing are complete, while OD PMT+WLS units and mPMTs have progressed from design to production, testing and assembly.

Testing shows promising performance across all three systems, with results in good agreement with expectations and tested photosensors meeting requirements.

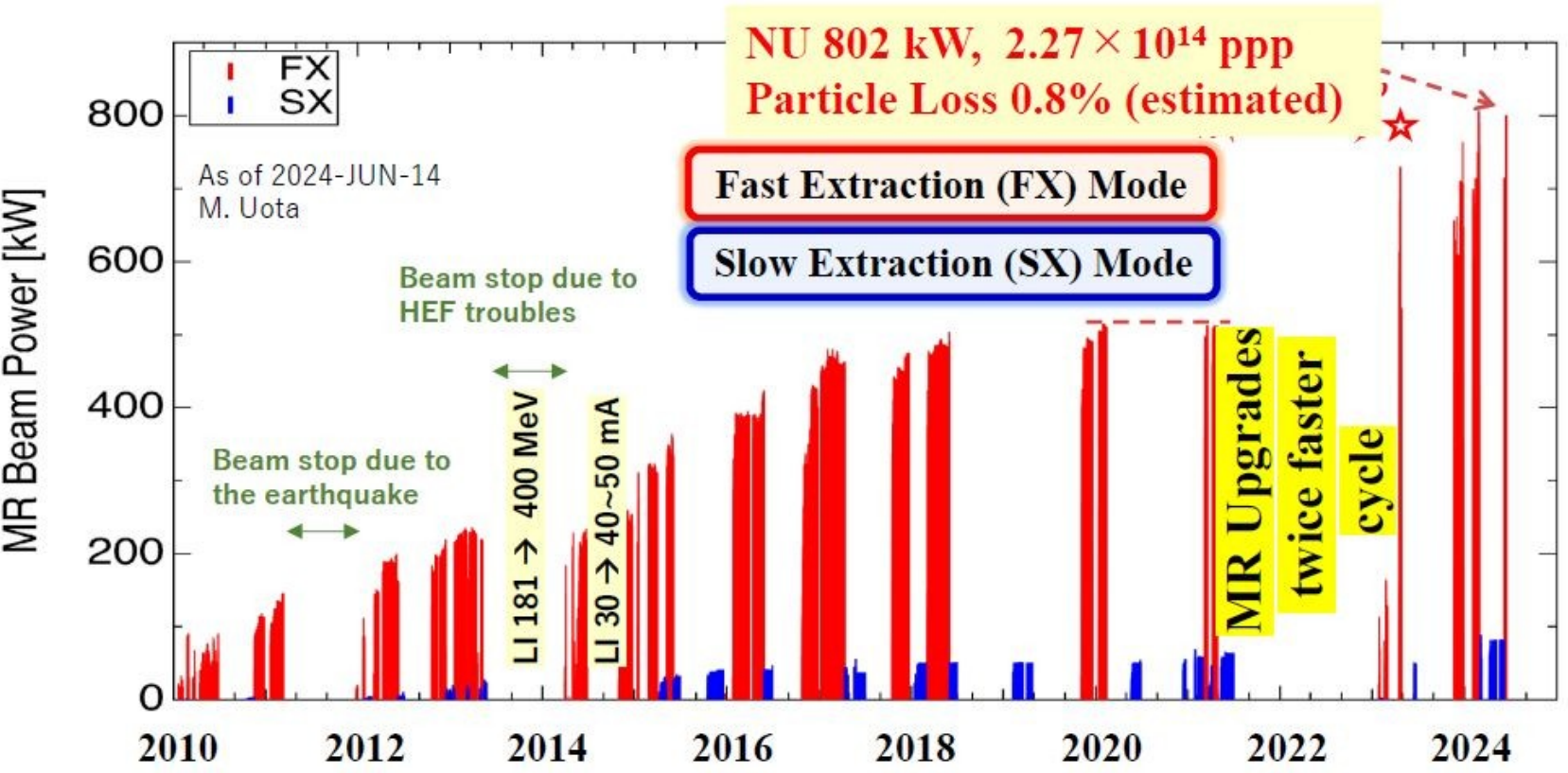
Thank you!

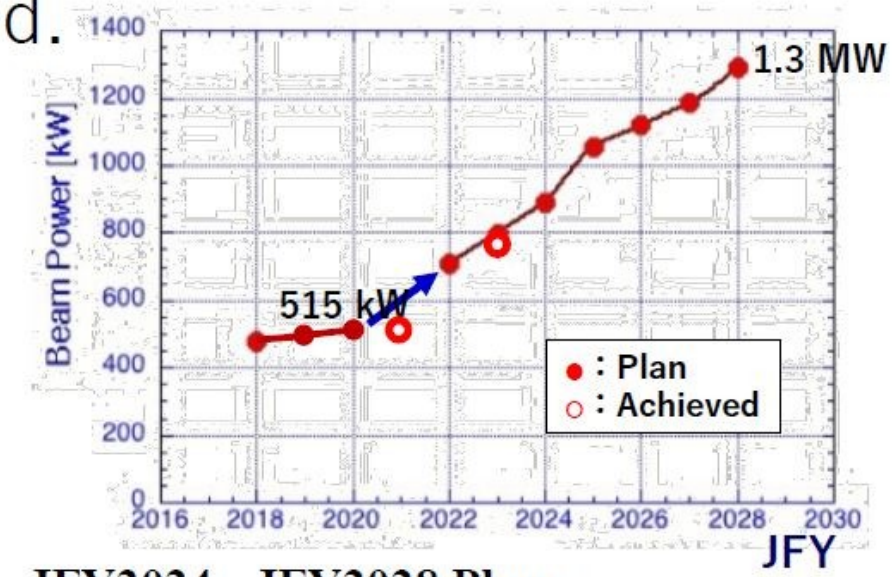


Backup

J-PARC Accelerator (MR) upgrade status

- Stable continuous **~800kW** (FX) operation for users is established!
  : MR power is being improved almost as planed.





JFY2024 - JFY2028 Plans

- RF system upgrade (continued)
- More magnet power supplies for beam correction
- Reinforcement of the main magnet PSs
- Upgrade MR-Abort-Dump

3.52s 3.04s 2.56s 2.48s → 1.36s → FX operation cycle for NU

6.00s → 5.52s → 5.20s → 4.24s → SX operation cycle for HD

By courtesy of Y. Sato (J-PARC Accelerator)

J-PARC KEK IPNS Institute of Particle and Nuclear Studies

New intermediate detector

Fully equipped with multi-PMTs = 19 x 3” PMTs assembles into a “big” PMT

- Far detector will also use 800 mPMTs

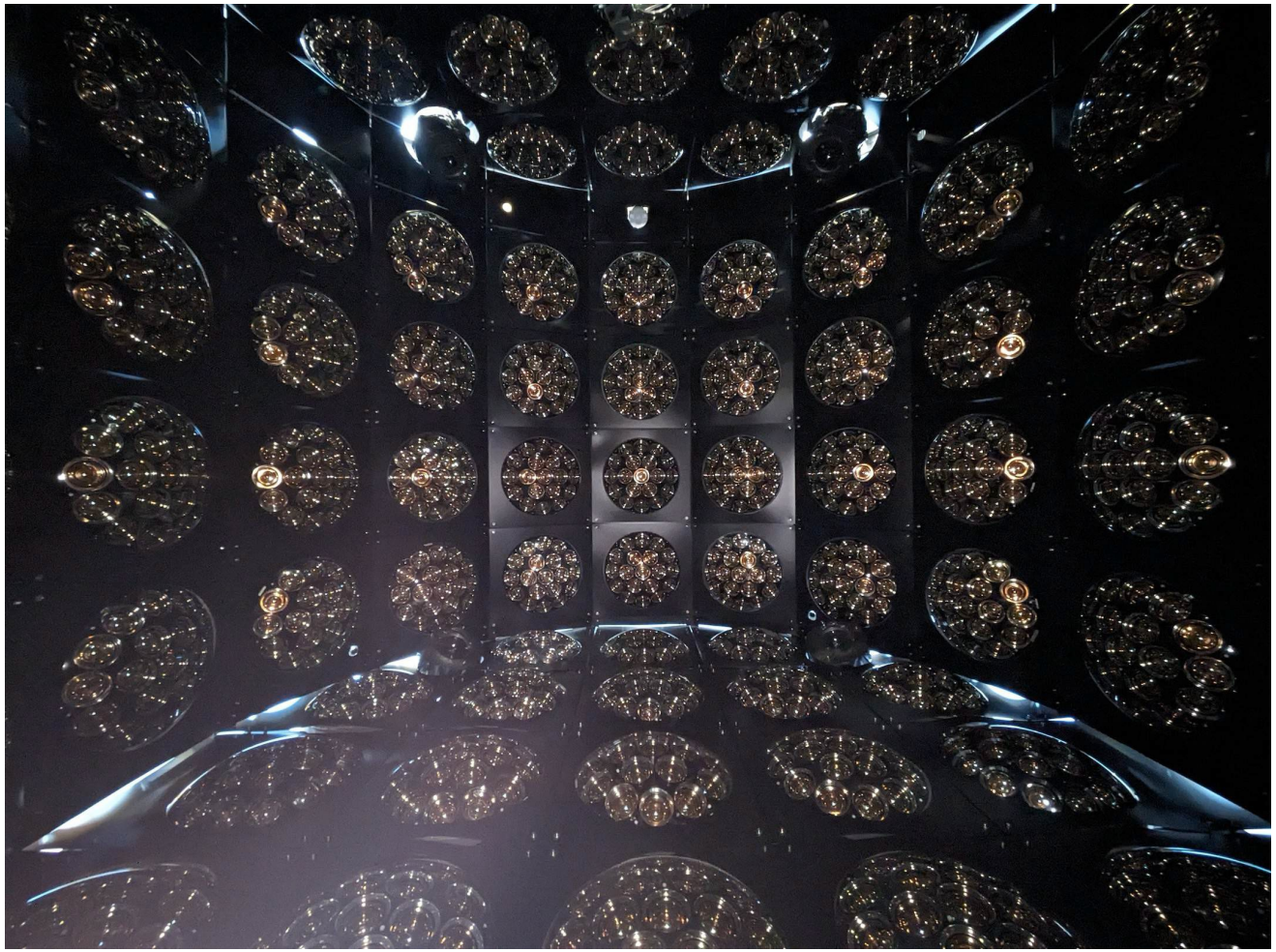
Benefits of mPMTs

- Superior photon counting
- Improved angular acceptance
- Extension of dynamic range
- Intrinsic directional sensitivity
- Local coincidences

Results in better vertex and angular resolution

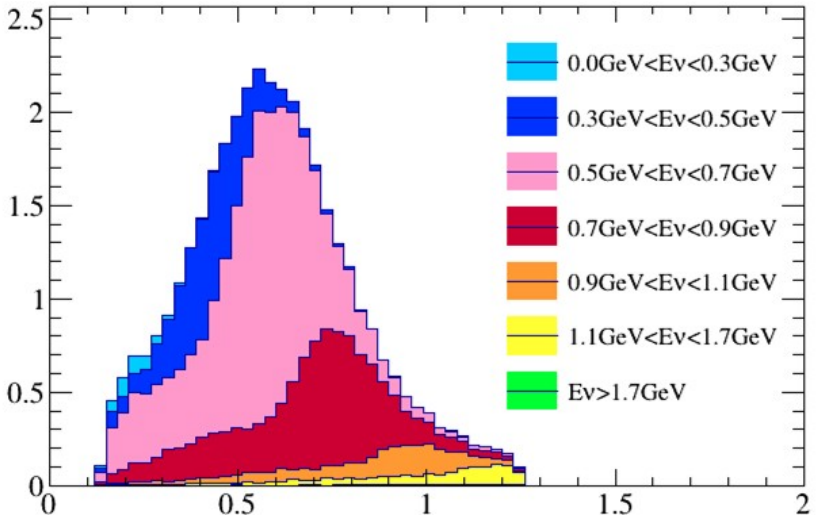
Improvement strongest near detector edges

Photo from WCTE in CERN

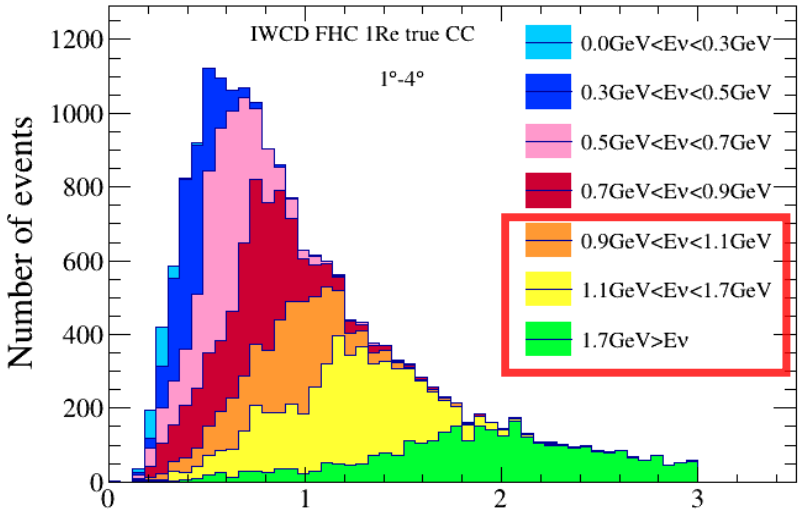


multi-PMT and IWCD physics case

Far Detector



IWCD



Non-QE backgrounds

Muon particle gun

