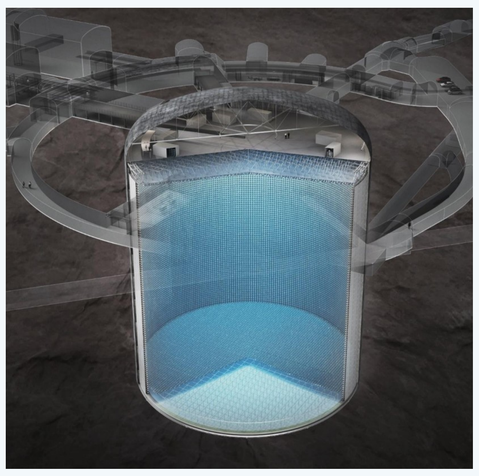
Large scale measurement of the performance of the Hyper-Kamiokande 50cm PMTs

C. Bronner*, S. Miki, K. Nakagiri, Y. Nishimura, T. Tashiro
on behalf of the Hyper-Kamiokande collaboration

1. Hyper-Kamiokande experiment

Hyper-Kamiokande: next generation water Cherenkov experiment in Japan

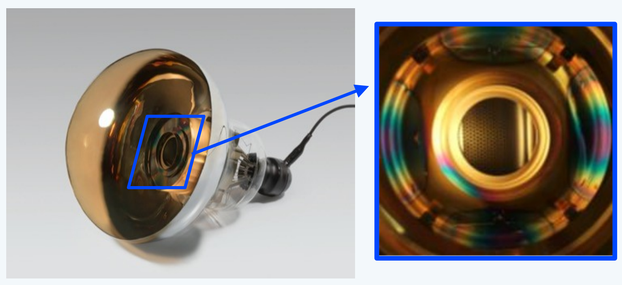


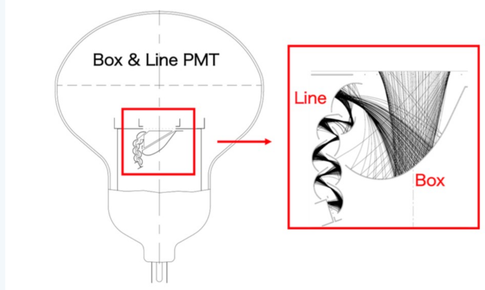
- **Large ultra-pure water tank**:
  72 m x 68 m, 188.4 kton fiducial volume
- **Broad physics program**:
  - Atmospheric neutrinos
  - Accelerator neutrinos
  - Solar neutrinos
  - Supernova neutrinos
  - Proton decay
  - Dark matter indirect detection
- Will start operation in 2027

Inner detector will be instrumented with **20000 high performance 50cm diameter Photo-Multiplier Tubes** (50cm PMTs)

2. Hyper-Kamiokande 50cm PMTs

Hyper-Kamiokande selected **R12860 model from Hamamatsu Photonics**
50 cm diameter PMT with “Box & Line” dynode

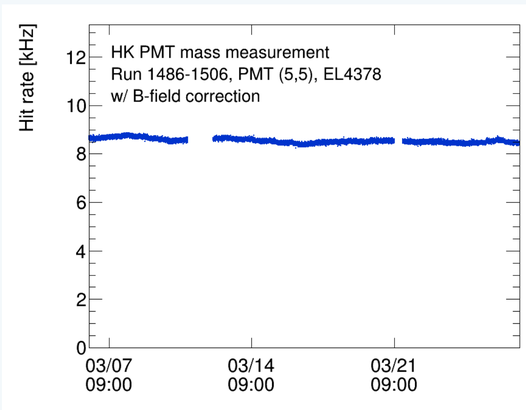




- **Improved performance** compared to R3600 model used in Super-K:
  - Factor 2 improvement in detection efficiency and charge resolution
  - More than factor 2 improvement in timing resolution
- Mass production on-going, **regular measurements by Hyper-K collaboration for quality control**
- Two mass production periods: before 2023, and since Jan. 2023

3. 200 PMTs measurement setup

Setup built to be able to test a significant fraction of produced PMTs:
- 2 rooms, each 100 PMTs capacity
- Perform **1 or 3 months measurements for quality control**
- Uses Super-K electronics to measure dark rate at different thresholds



- **Look at rates of PMTs over 1 or 3 months**
- **Check for potential issues**:
  - High dark rate (>10 kHz after corrections)
  - Rate instabilities (2 failure criteria)
  - Light emission from discharges (“flashers”), appear as correlated rate increase in nearby PMTs

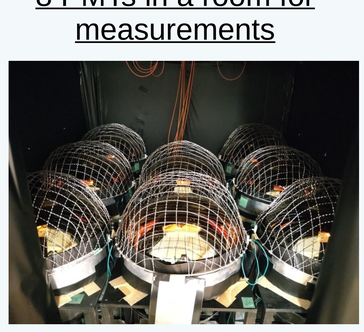
1478 PMTs tested using this setup since Apr. 2023
Failure rate lower than requirements (<1% flashers and <5% total failure)
Tested PMTs satisfy Hyper-K requirements for failure rates

4. 16 PMTs measurement setup

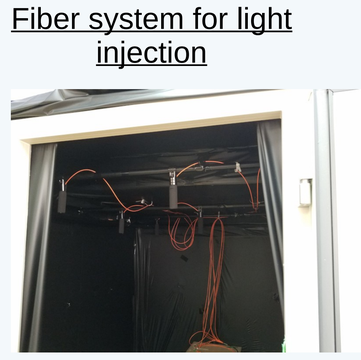
- Two 8 PMT rooms for measurements of various properties of the PMTs
- Uses VME electronics to **measure rate, charge and timing of hits**
- Light source for **Single Photo-Electron spectrum** and **timing response** checks
- Mu-metal used to shield from geomagnetic field

Outside view of the two rooms

8 PMTs in a room for measurements



Fiber system for light injection

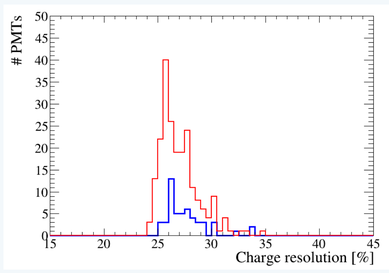


Precise measurements for a fraction of delivered PMTs:
- **Check PMTs performance satisfy requirements**
- **Check for variation of performance between different PMT batches**

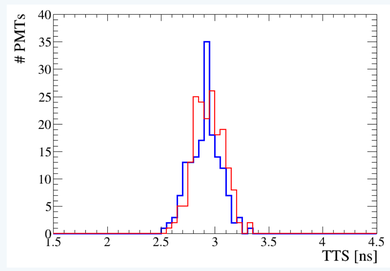
5. Performance measurements

Using 16 PMTs setup, measure (among others) following quantities:
- Charge resolution: width of single photo-electron peak / distance between this peak and pedestal
- Timing resolution (“TTS”): FWHM of hit time distribution
- Afterpulse: delayed correlated hit after a hit is detected

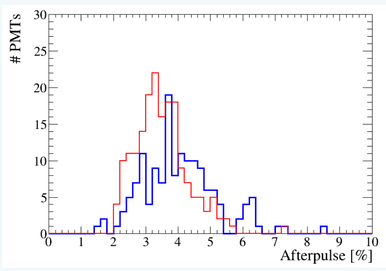
Charge resolution



Timing resolution



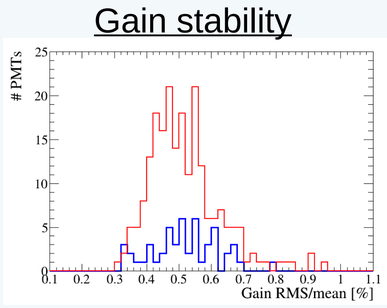
After-pulse



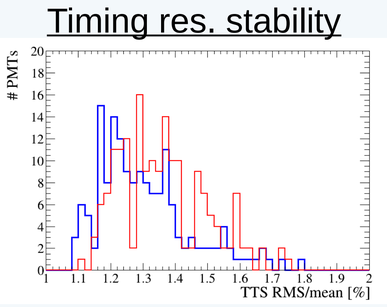
PMTs delivered before and after Jan. 2023

Stability in time: separate 1-2 weeks measurements into blocks of 500k events, and look at RMS/mean of values measured in the different blocks (requirement: <2%)

Gain stability



Timing res. stability



	Charge resolution [%]	Timing resolution [ns]	After-pulse [%]	Gain stability [%]	Timing res. stability [%]
Pre-2023 PMTs	27.6 ± 1.9	2.90 ± 0.14	4.04 ± 1.2	0.52 ± 0.10	1.31 ± 0.14
PMTs after Jan. 2023	27.0 ± 1.8	2.94 ± 0.14	3.50 ± 0.83	0.52 ± 0.11	1.36 ± 0.13

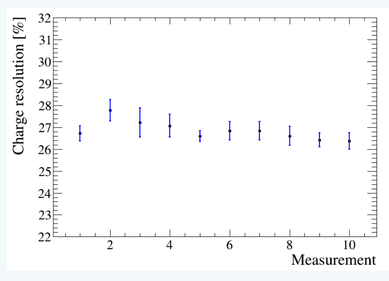
Values quoted are mean ± RMS of histograms above
Total number of PMTs measured varies between 250 and 350 depending on quantity measured

All PMTs tested in this setup satisfied HK performance requirements

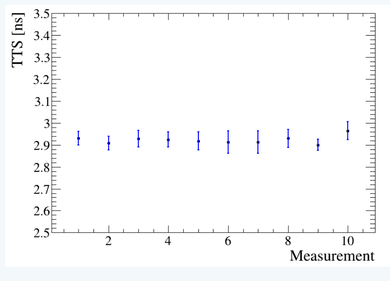
6. Stability of production quality

- Checked by comparing results of measurements done on PMTs from different deliveries
- Plots show **mean (point) and RMS (error bar) over the 15 PMTs tested from each of the deliveries done in 2023**

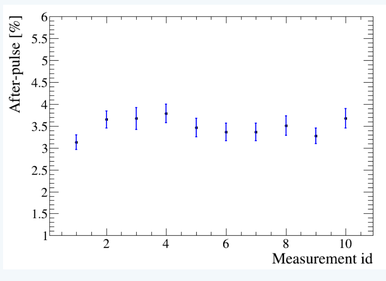
Charge resolution



Timing resolution



After-pulse



Performance of the PMTs found to be consistent between the different 2023 deliveries