

The front end electronics of the Hyper Kamiokande far detector



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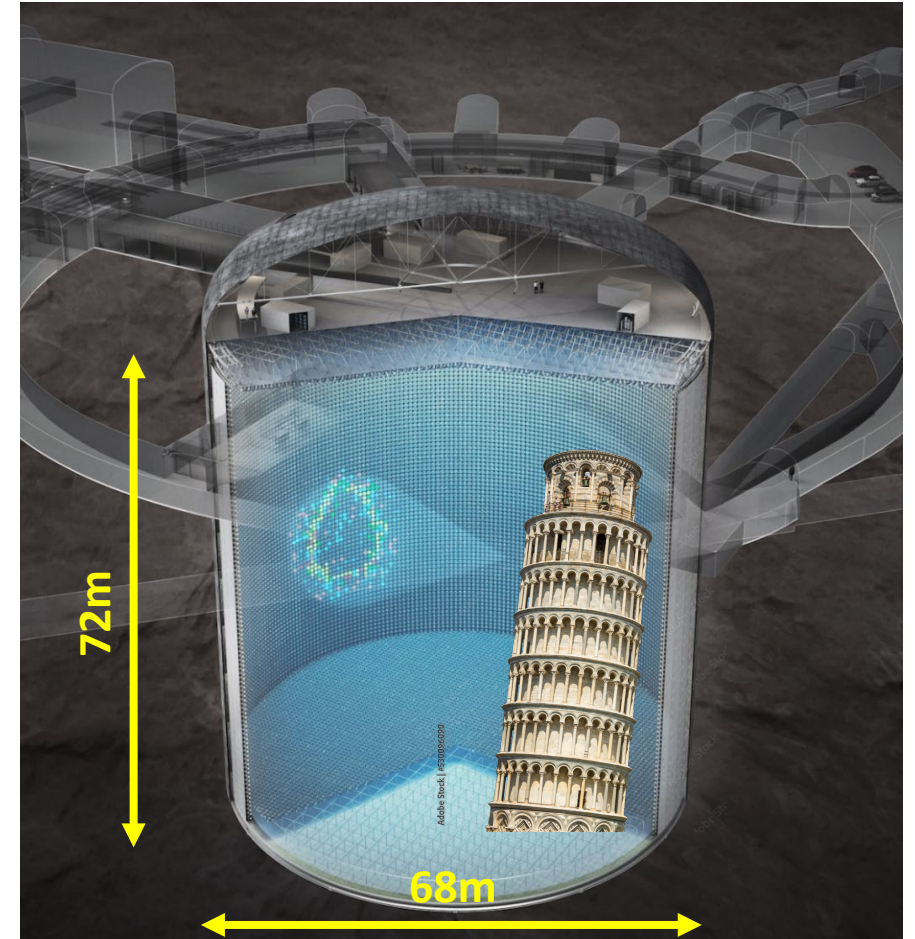
REAL TIME CONFERENCE
26/05/2026

ON BEHALF OF HYPER KAMIOKANDE GROUP

Hyper-Kamiokande

Hyper-Kamiokande (Hyper-K) is the next-generation water-Cherenkov neutrino experiment, building on the success of Super-Kamiokande and T2K to extend sensitivity through much larger detector mass and improved reconstruction performance.

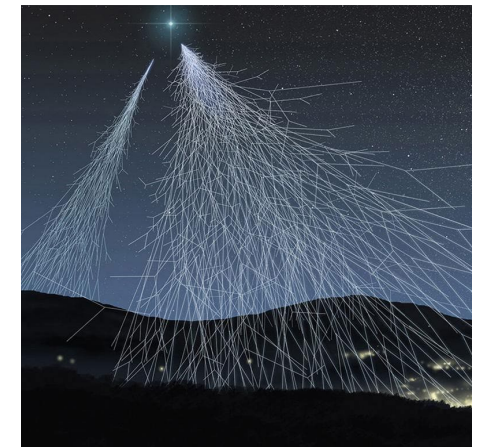
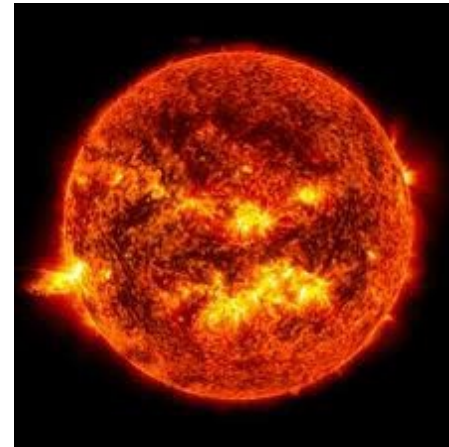
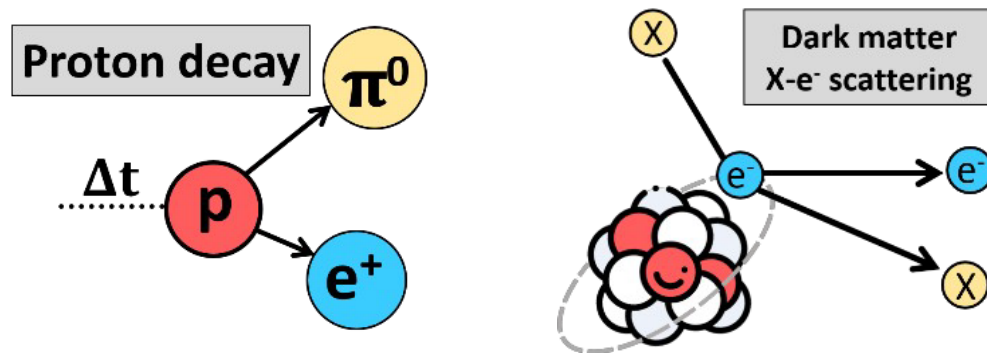
- Operations are expected to begin in 2028.
- The detector features a 260 kton water tank (fiducial volume ~ 190 kton)
 - 8 times larger than Super-Kamiokande.
- It will be instrumented with about 20,000 20-inch PMTs,
 - a factor 2 of improvement in detection efficiency and charge/time resolution.
- Hyper-K is part of the long-baseline neutrino program with J-PARC (295Km), supported by near (280m) and intermediate detectors (850m)



Physics program

Hyper-K enables a broad and ambitious physics program spanning neutrino physics, astro-particle physics, and searches for rare processes.

- Accelerator and atmospheric neutrinos
 - mass ordering
 - CP violation
- Solar and supernova neutrinos.
- Proton decay searches
- Dark matter searches



Hyper-K Far Detector

New monolithic detector for unprecedented neutrino interaction detection rate

600 m below Mt. Nijyugo-yama near Kamioka

71 m tall x 68 m diameter tank

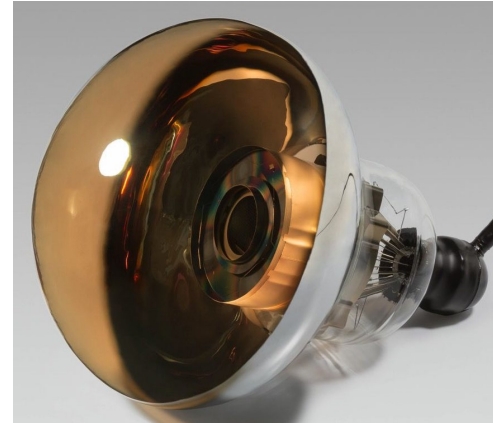
- 8 x increase in fiducial mass over Super-K

New photo-detector technology

- 20,000 50cm (20-inch) PMTs
- 2x improved detection efficiency and timing resolution
- 20% photo-coverage
- 1.5 ns timing res. (half SK)

Additional coverage from multi-PMT modules

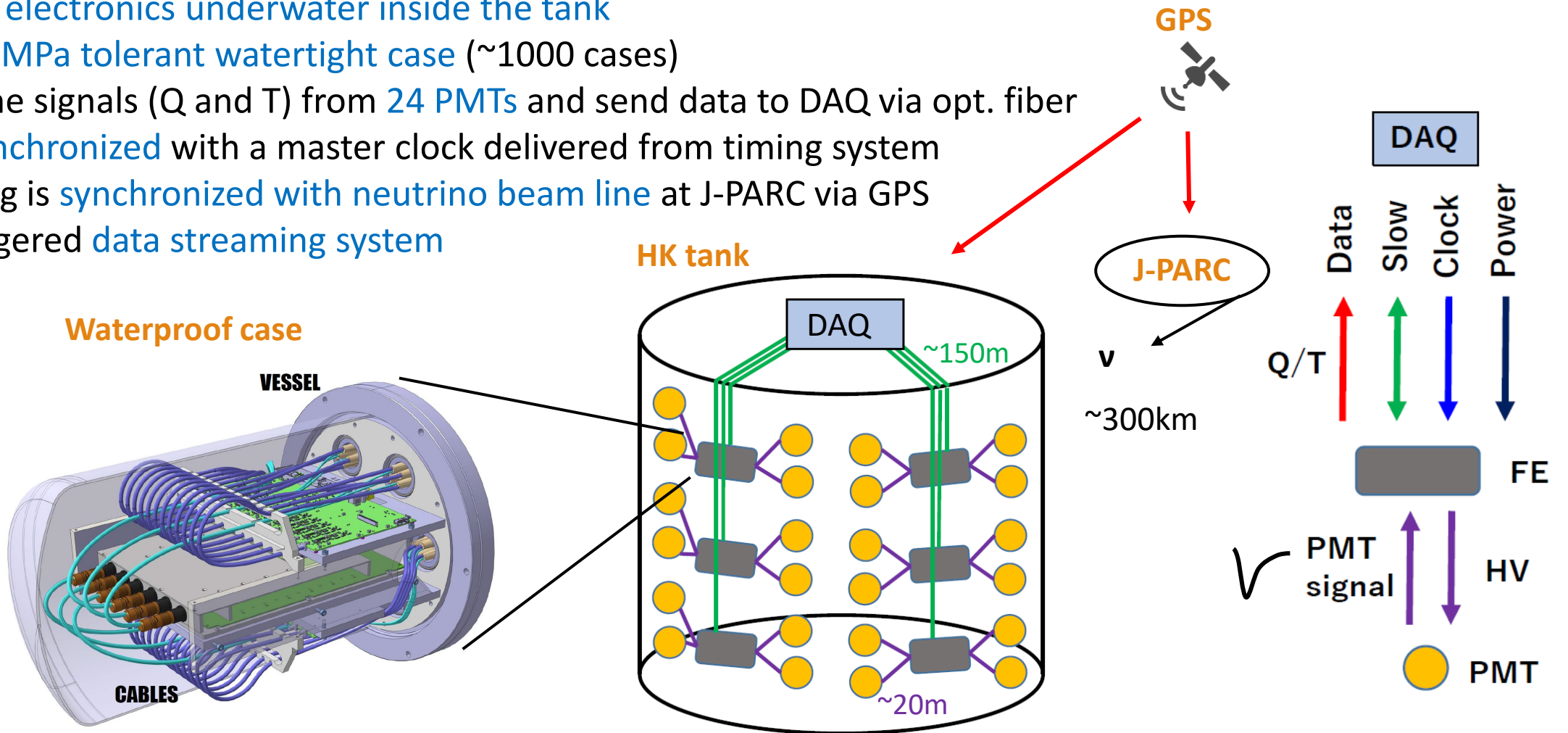
- 19 x 8cm PMTs inside 50cm sealed vessel
- Improved directional resolution, dark rate, calibration



HK Electronics

Frontend electronics is placed under water inside the HK tank (It was outside the tank in SK)

- The cable length and weight, together with the additional cost of the support structure, led us to place the electronics underwater inside the tank
- Inside a 1MPa tolerant watertight case (~1000 cases)
- digitize the signals (Q and T) from 24 PMTs and send data to DAQ via opt. fiber
- FE are synchronized with a master clock delivered from timing system
- Everything is synchronized with neutrino beam line at J-PARC via GPS
- Auto-triggered data streaming system



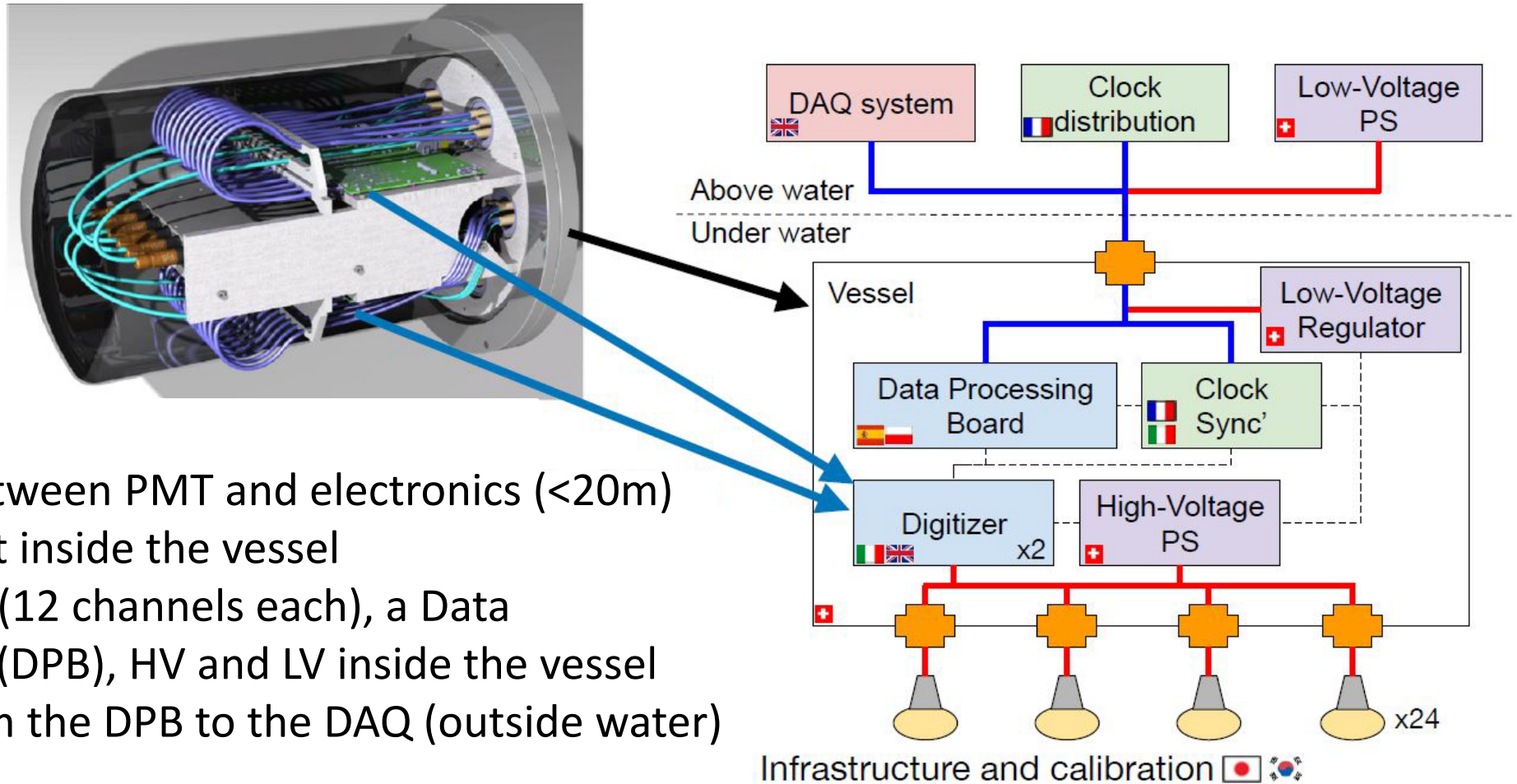
HK Elec. Requirements

- Rich physics programs require wide range in energy and event rate
- High performance HK PMT requires both an high dynamic range in charge and high resolution in charge and timing
- Underwater environment sets additional constraints (watertight, heat control, failure rate, etc)
- HK Elec. is requested to have equal or better performance than SK Elec. to exploit the new, higher-performance PMTs

| Test items | Signal type | Requirements |
|-------------------------|-------------|--|
| Discriminator threshold | FG & PMT | Settable to 1/6 p.e. (-1 mV) |
| Charge linearity | FG | $< \pm 1\%$ (1 p.e.-1,250 p.e.) |
| | PMT | $< \pm 1\%$ (1 p.e.-100 p.e.) |
| Charge resolution | FG | < 0.19 pC (< 19 pC=10 p.e., 200 ns) |
| | | $< 1\%$ (> 19 pC=10 p.e., 200 ns) |
| | PMT | < 0.19 pC (< 19 pC=10 p.e., 400 ns) |
| | | $< 1\%$ (> 19 pC=10 p.e., 400 ns) |
| Timing resolution | FG | < 300 ps (1.9 pC=1 p.e.) |
| | PMT | < 200 ps (9.5 pC=5 p.e.) |
| Crosstalk | FG & PMT | $< 1/1,000$ for 2,375 pC |

| | HK Elec. | SK Elec. |
|-----------------|--------------|---------------------------|
| digitizer | Discrete ICs | ASIC |
| deadtime | 500ns | 1μs |
| time digit | 0.25ns | 0.5ns |
| buffer | 8GB | ~100MB |
| readout | 1Gbps | 100Mbps |

Underwater electronics vessel

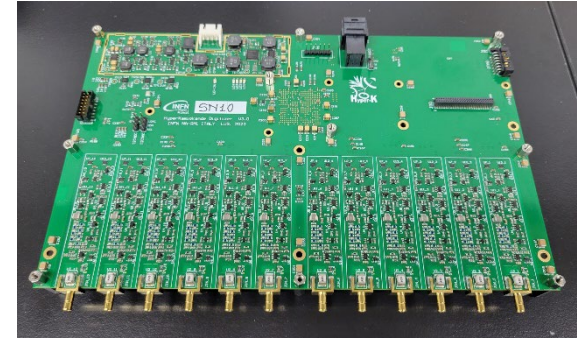


- Short distance between PMT and electronics (<20m)
- All signals brought inside the vessel
- 2 digitizer boards (12 channels each), a Data Processing Board (DPB), HV and LV inside the vessel
- Data are sent from the DPB to the DAQ (outside water)

Frontend boards

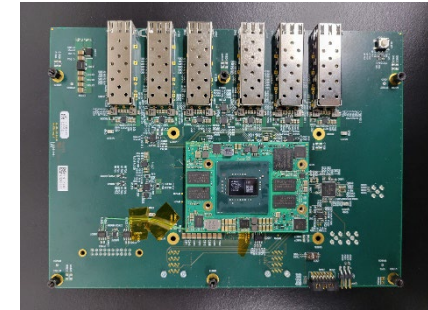
Digitizer board (12ch) x 2

- digitize PMT waveform measuring Charge and Time
- made by discrete analog component
- integrator & ADC
- FPGA TDC



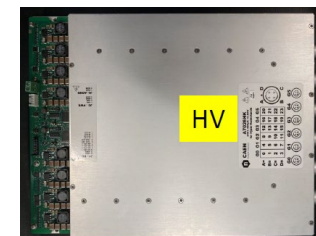
Data Processing Board

- process digitizer hits and send them to DAQ with 1Gbps links
- slow control
- timing distribution



HV/LV board

- 48V input (2A) <100W
- HV ~2.5kV for 24 PMTs



HK Digitizer

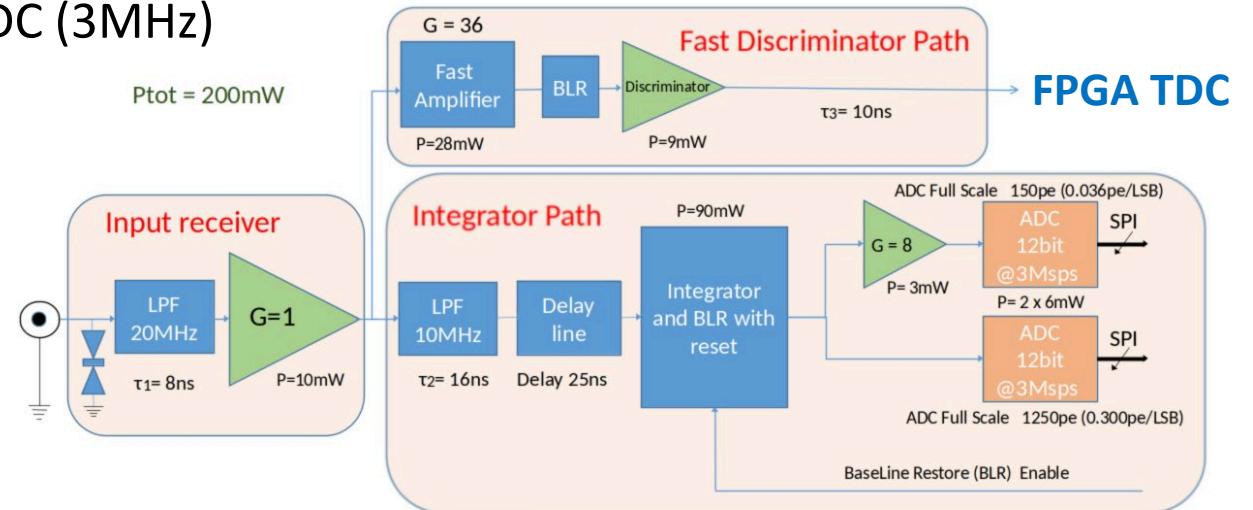
Discrete design (Xilinx Kintex-7) with 2 separated paths:

- **Q path:**

- output of an analog integrator sampled by a SPI-ADC (3MHz)
- 2 ranges to cover 2350pC (1x and 8x gain)
- 1% linearity
- 500 ns dead time

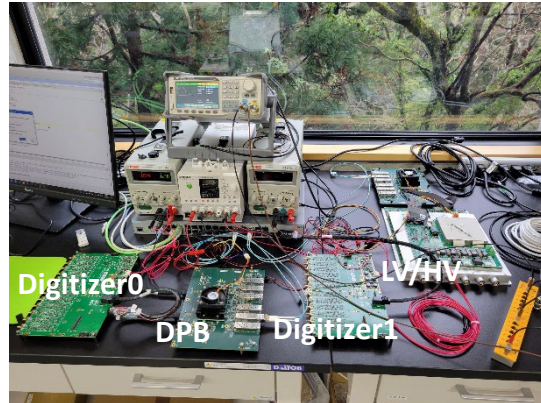
- **T path:**

- Analog discriminator
- Per-channel thresholds set via DAQ
- FPGA multi phase TDC (clk 500MHz x 8 phases)
- 250 ps LSB
- ToT measured even during the dead time

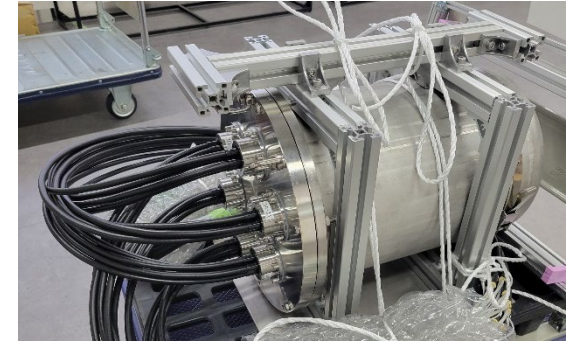
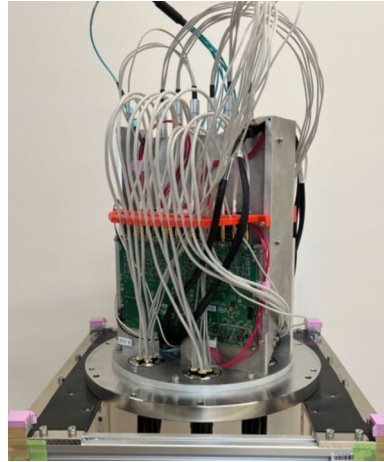


Tests

Test of the entire read-out chain



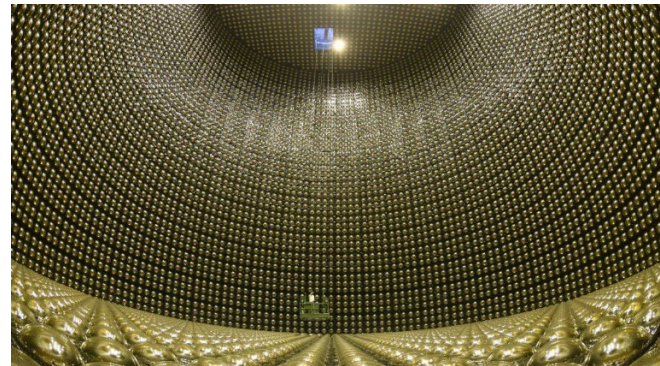
Test of the integration in the stand and in the watertight vessel



Test with HK PMT

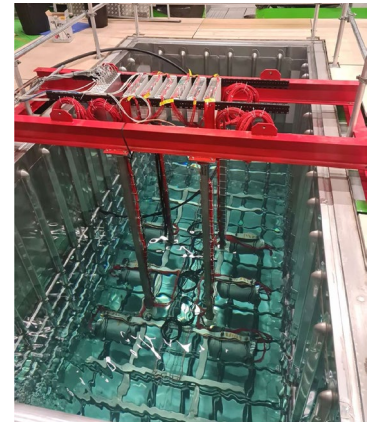


Test using SK experiment



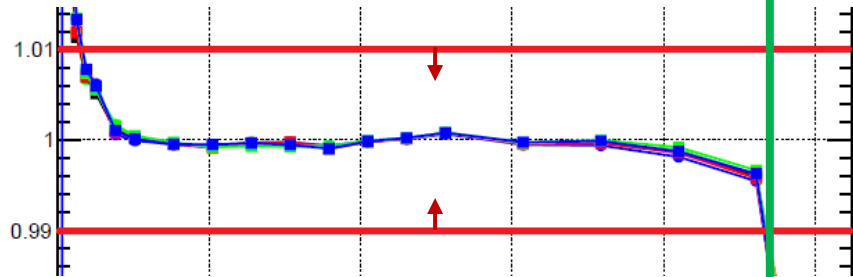
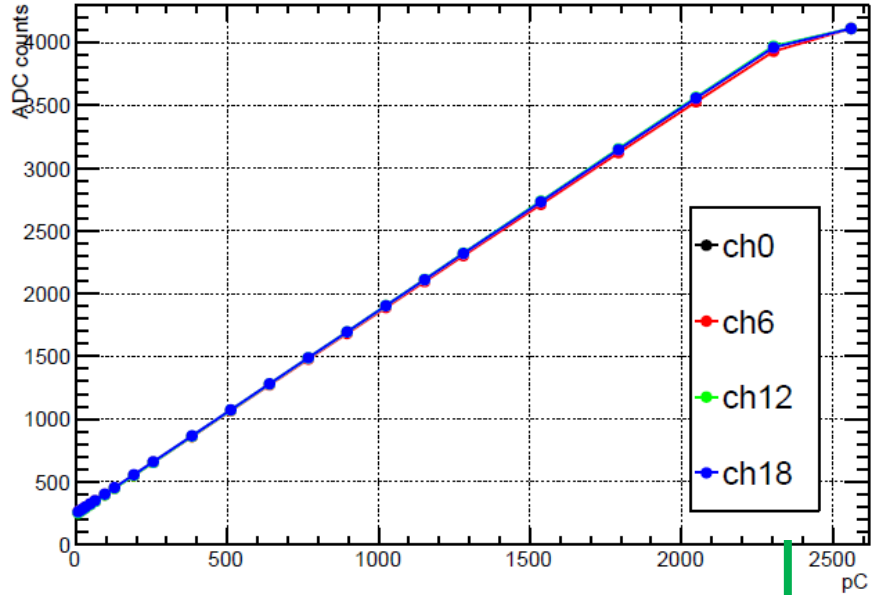
(C) Kamioka Obs., ICRR, The Univ. of Tokyo

Under water test



Charge linearity (Function Generator)

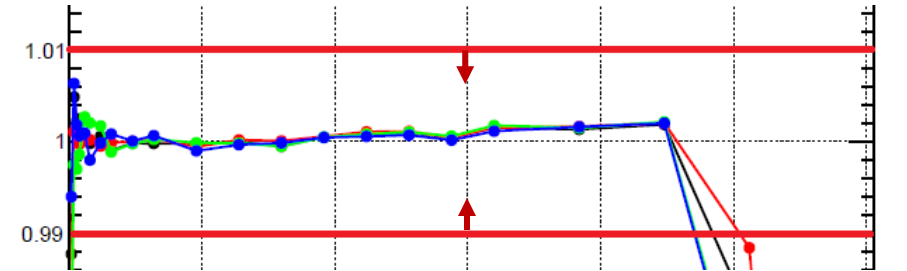
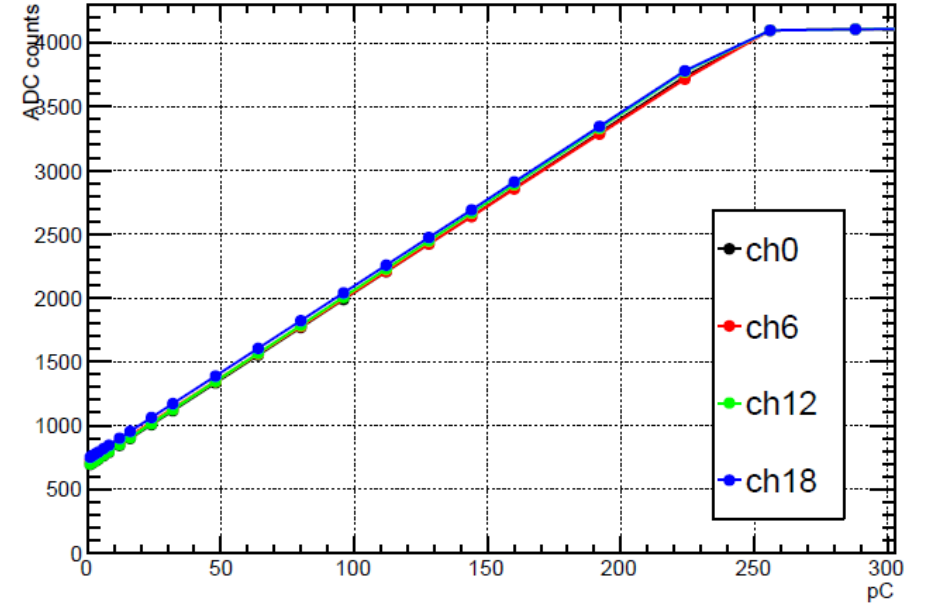
Low Gain Charge (400ns)



1250 p.e.

Requirement $< \pm 1\%$
(1 p.e. – 1250 p.e.)
1 p.e. = 1.92 pC

High Gain Charge (400ns)



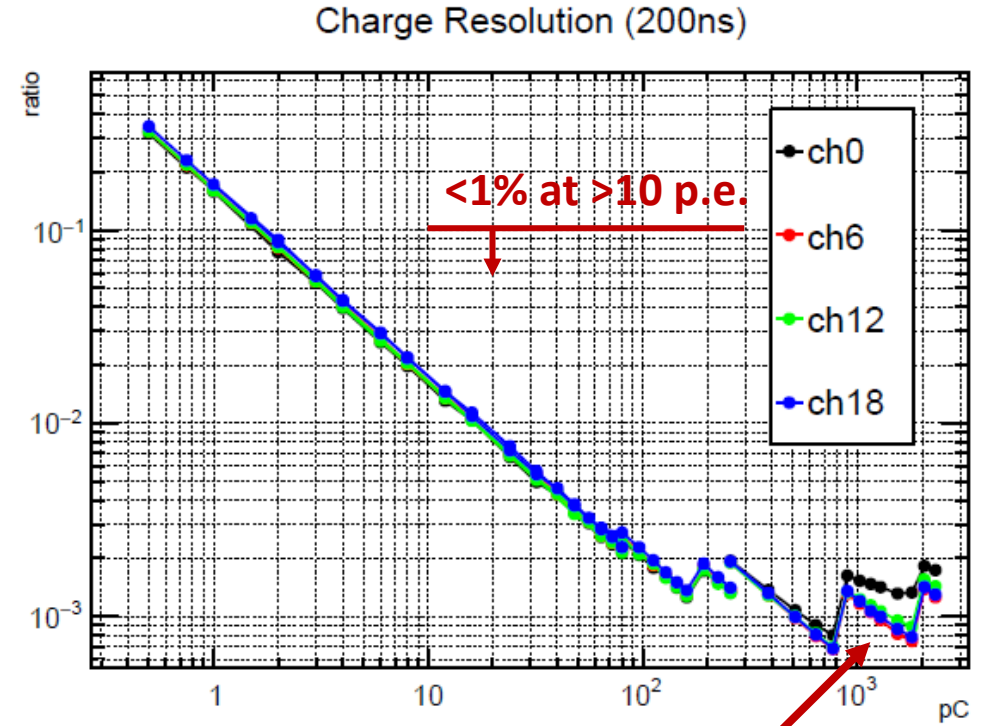
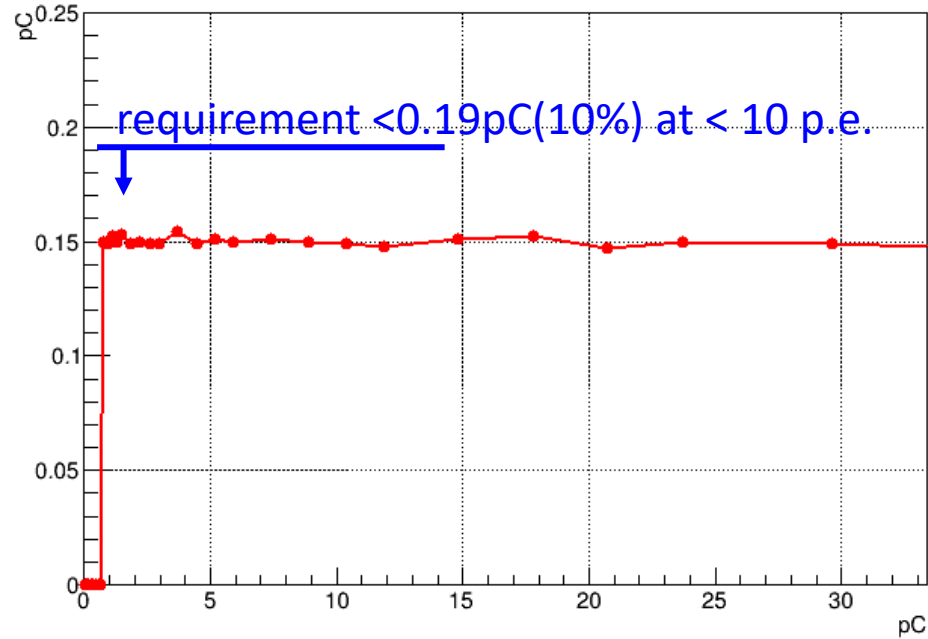
Charge Resolution (Function Generator)

Charge resolution

FG

$< 0.19 \text{ pC}$ ($< 19 \text{ pC} = 10 \text{ p.e.}, 200 \text{ ns}$)

$< 1\%$ ($> 19 \text{ pC} = 10 \text{ p.e.}, 200 \text{ ns}$)



Effect of the function generator

Time Resolution (Function Generator)

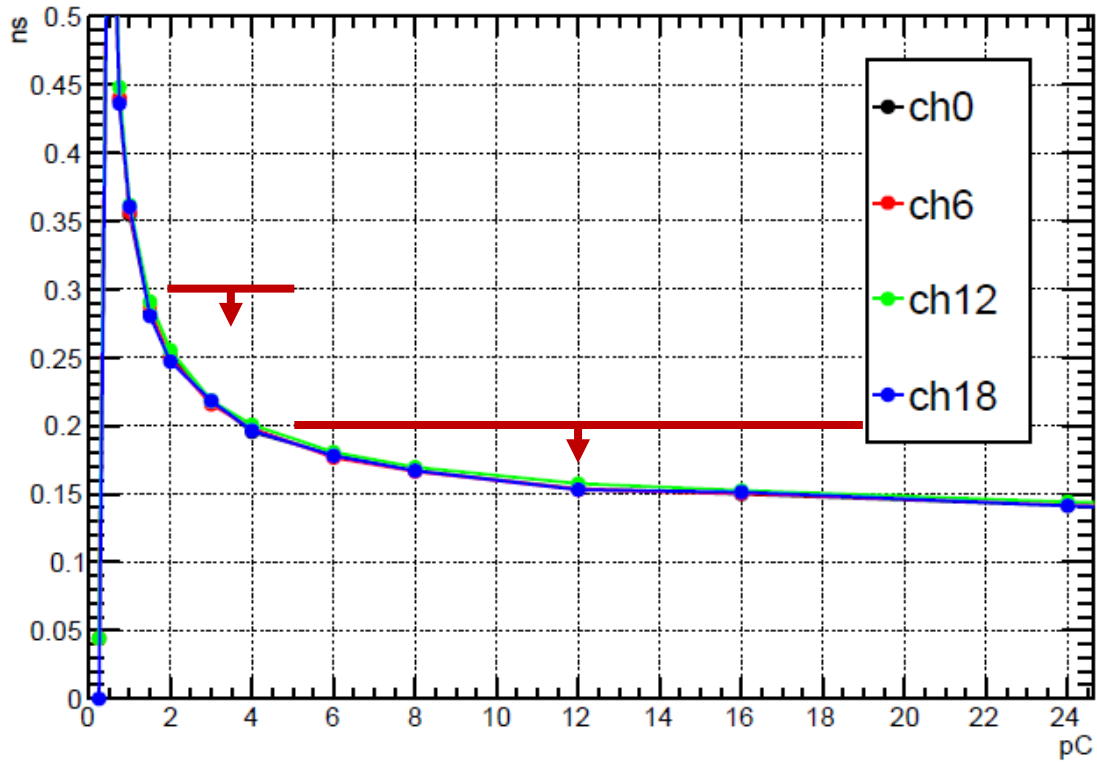
Timing resolution

FG

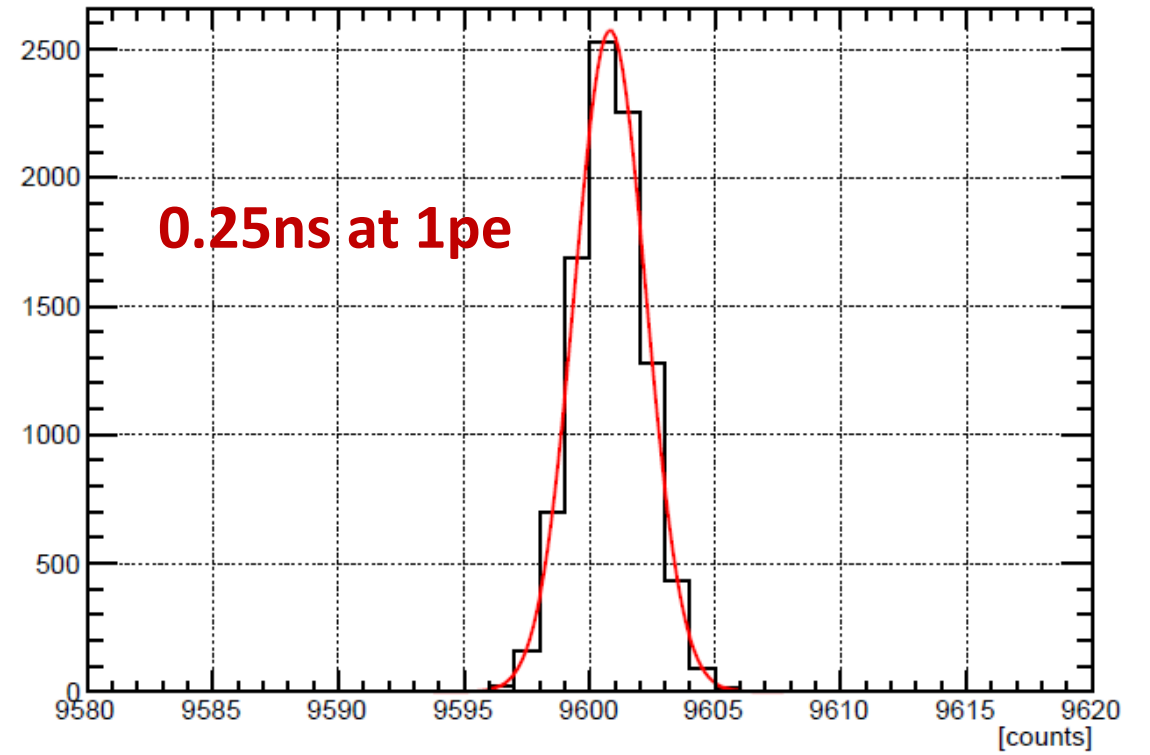
< 300 ps (1.9 pC=1 p.e.)

< 200 ps (9.5 pC=5 p.e.)

Timing Resolution



Time Difference (at 1 p.e.)



Test with Super-Kamiokande

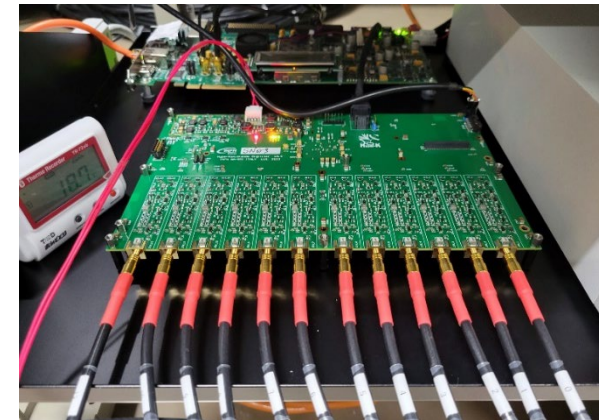
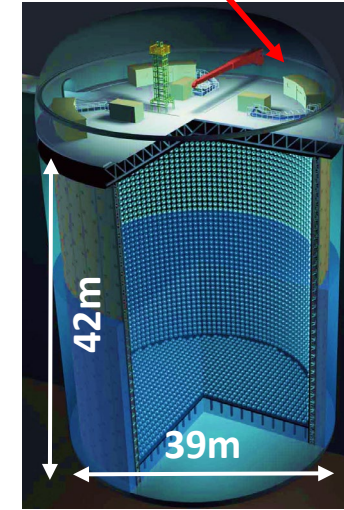
Realistic environment

- real Cherenkov detector with 20" PMTs (~11,000 PMTs)
- small number of HK PMTs are also installed for tests
- calibration sources are available in tank
- easy to compare SK Elec.

Setup

- FE is in electronics hut outside of SK tank
- tested a single HK digitizer board
- replaced 1 SK board with HK board
- The board was connected to 10 SK PMTs and 1 HK PMT
- Used the SK master clock for synchronization

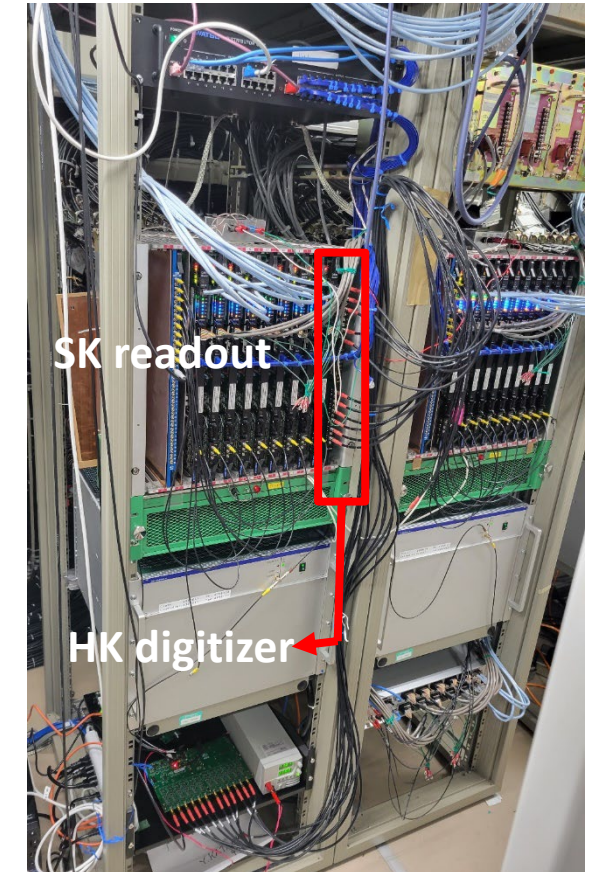
electronics Hut



SK MCLK

HK PMT

10 SK PMTs



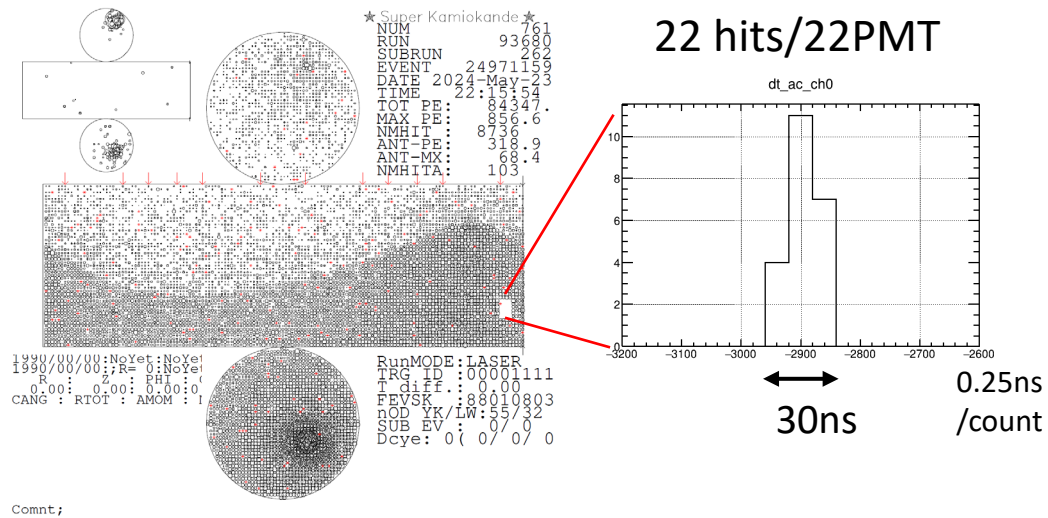
SK readout

HK digitizer

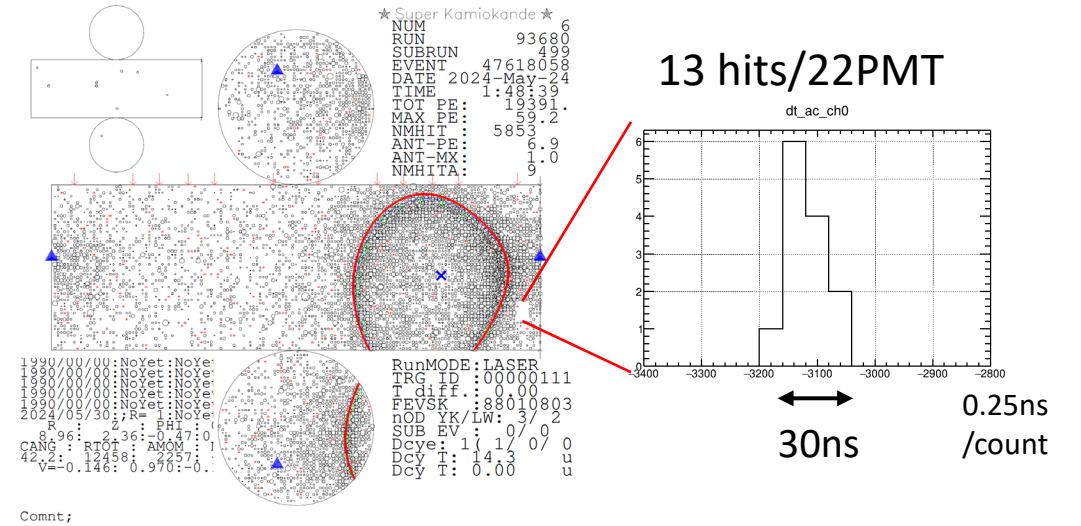
(C) Kamioka Obs., ICRR, The Univ. of Tokyo

SK Events recorded

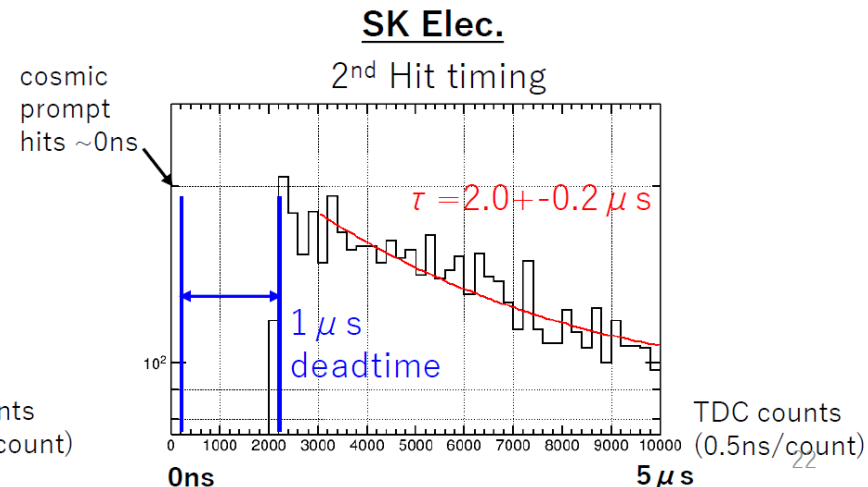
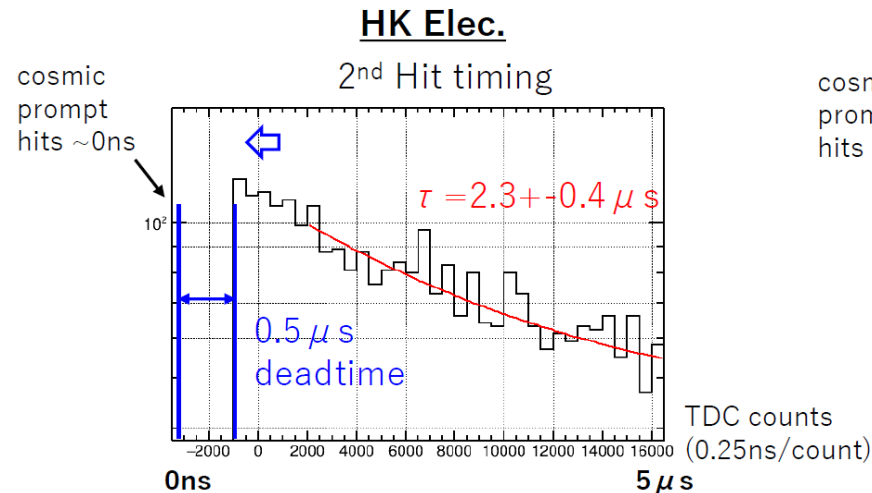
• Cosmic event



• Neutrino event



• μ decay e event



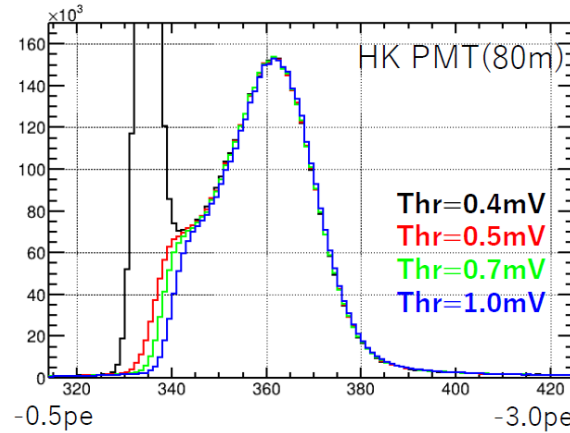
Charge and noise

Charge measurement (by dark hits)

- good resolution for single photon detection of HK PMT $\sim 32\%$ at 1pe (SK PMT $\sim 50\%$)
- no difference with SK electronics (resolution of electronics $\sim 10\%$ at 1pe)

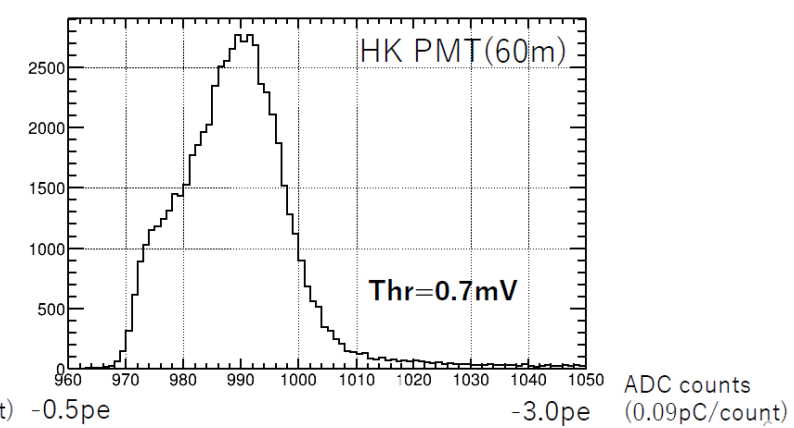
HK Elec.

Charge

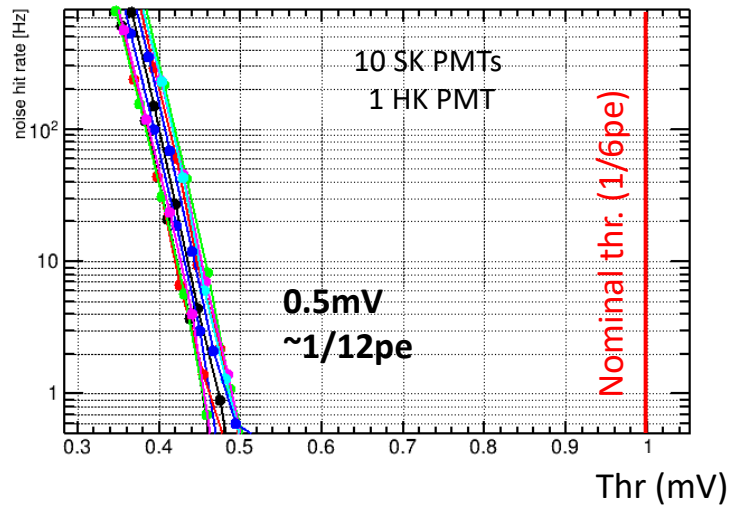


SK Elec.

Charge



Noise hit rate



Noise level

Noise level confirmed to be 0.5mV $\sim 1/12\text{pe}$
($<$ requirement 1/6pe)

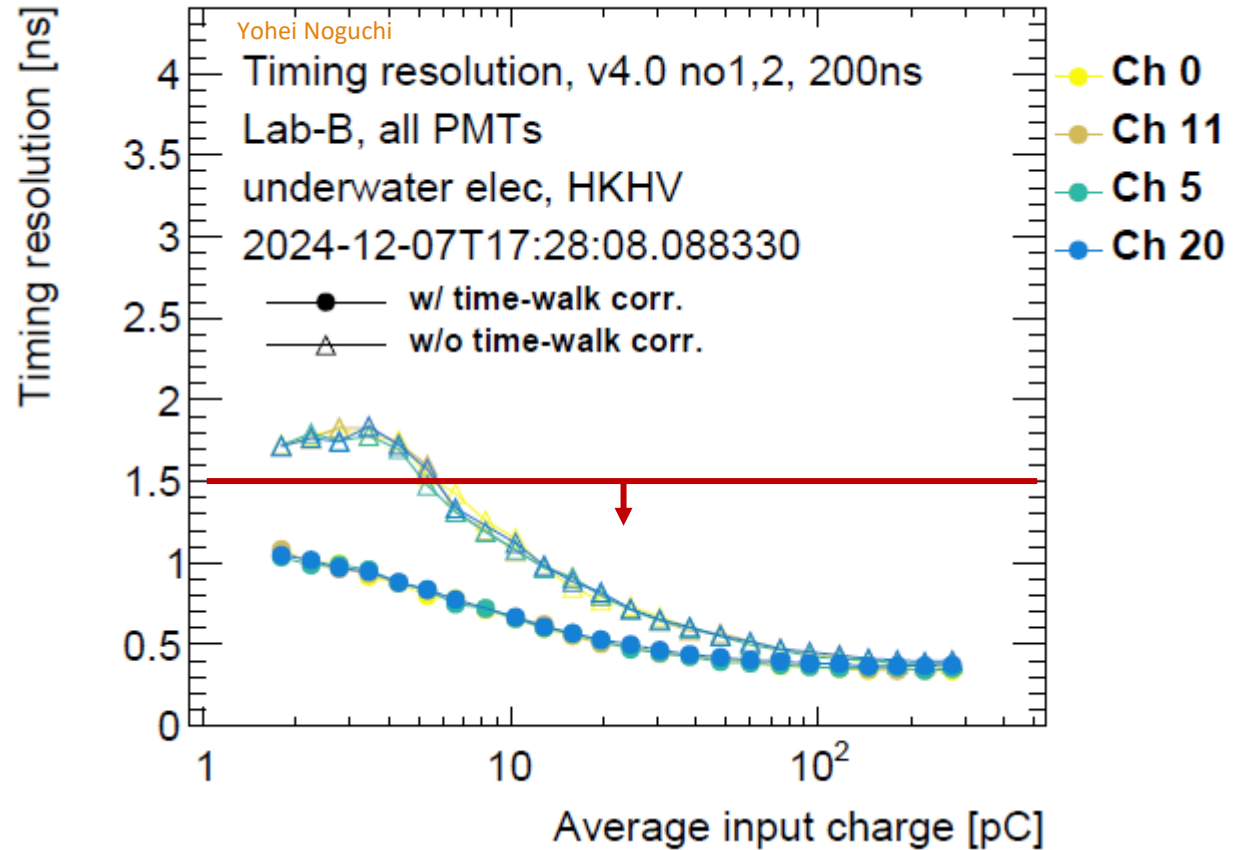
Time resolutions with PMTs

Timing resolution

PMT

< 1.5 ns (1.9 pC=1 p.e.)

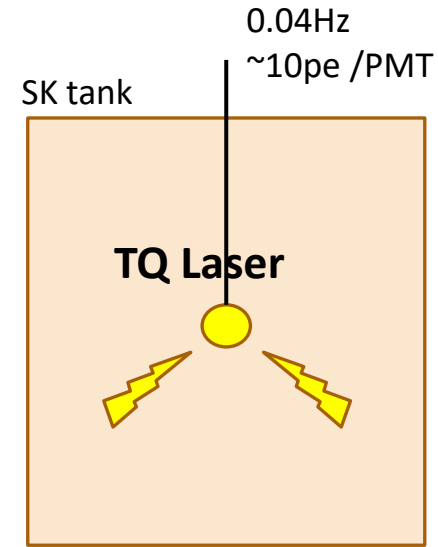
- Used laser diode source
- pulses at the lowest available rate (3 kHz)
- A time-walk profile is then used to correct the timing of hits
- The time-walk corrected resolution respect the requirement (<1.5 ns)



SK Events recorded

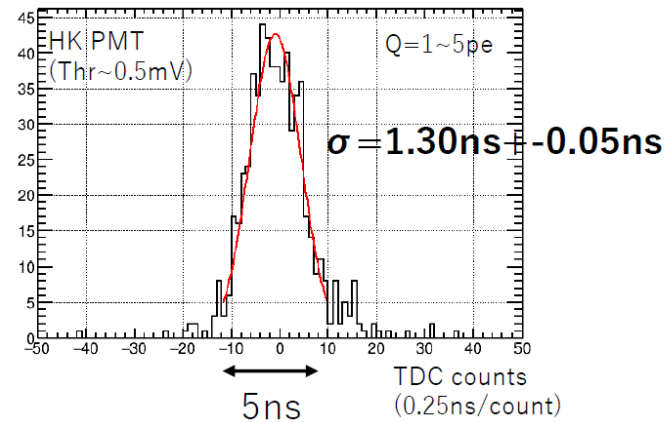
timing measurement

- Used the calibration laser source in SK tank
- resolution $\sim 1.3\text{ns}$ at 1-5pe
- no difference with SK electronics (resolution of electronics $\sim 0.25\text{ns}$)



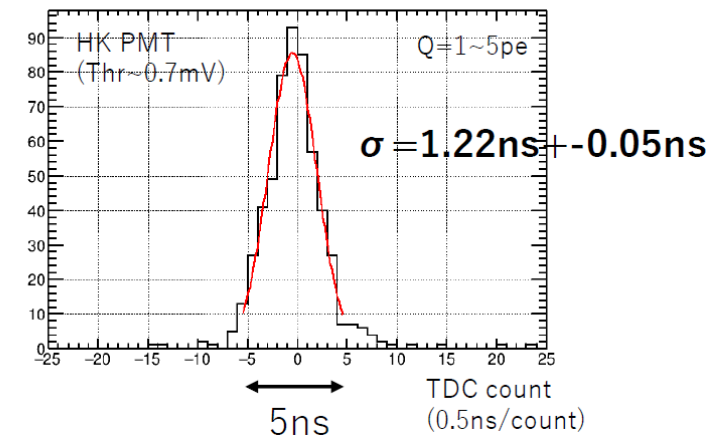
HK Elec.

Timing



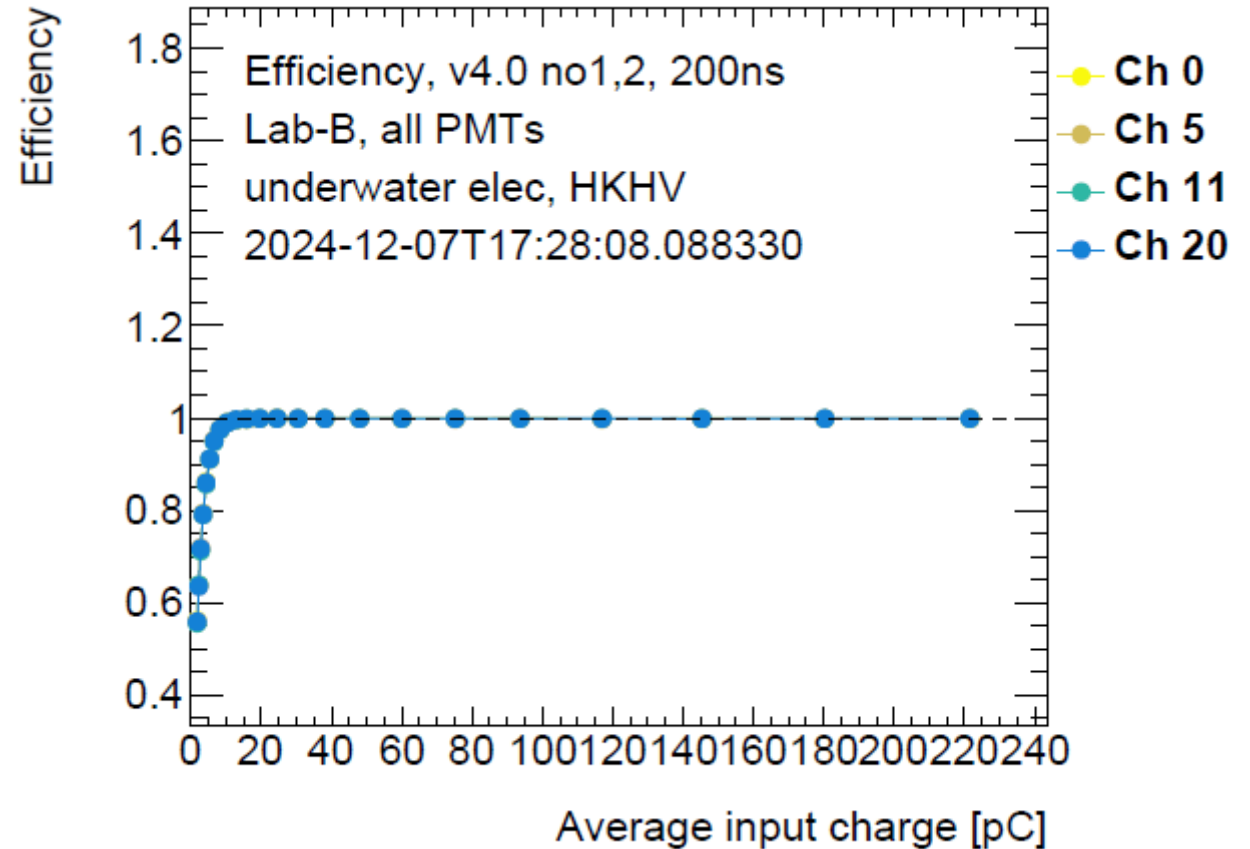
SK Elec.

Timing



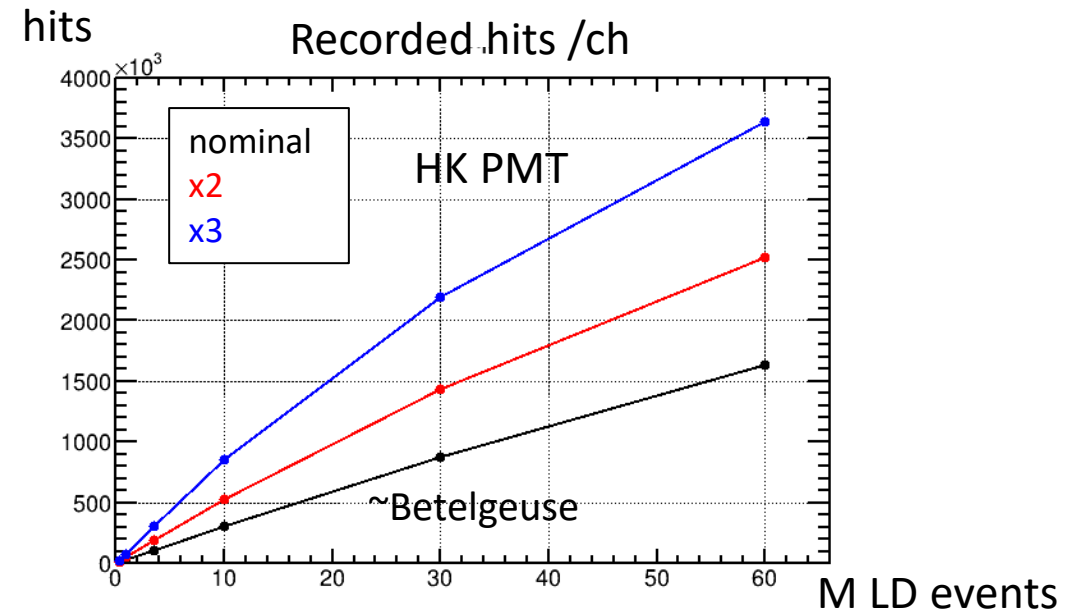
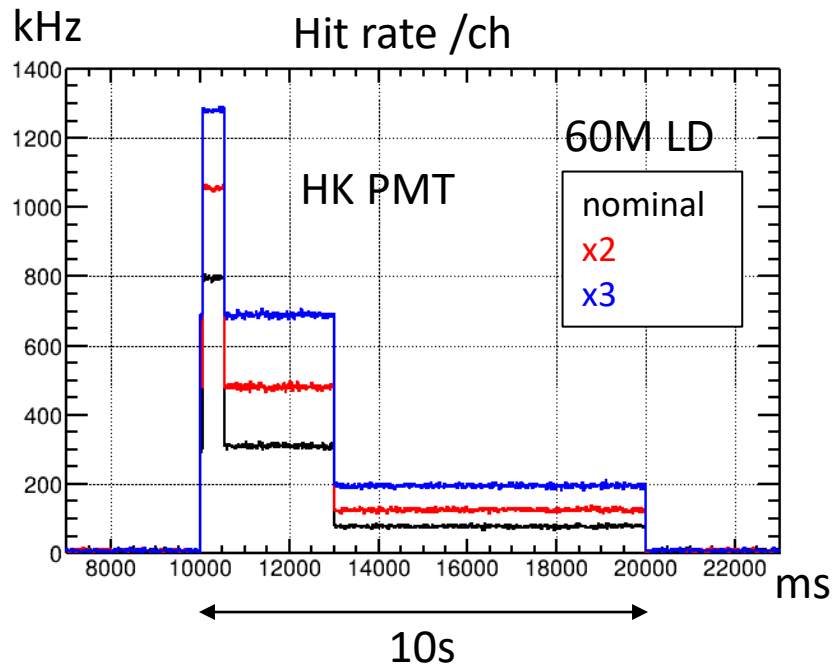
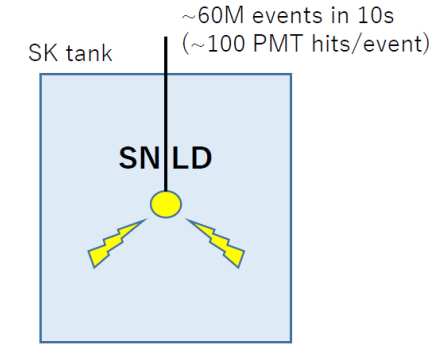
Channels efficiency

- We measured the efficiency as a function of the average input charge
- Used laser diode source at 3 KHz
- The denominator is defined as the number of trigger hits coming from the laser diode.
- 100% efficiency is found for the average charge greater than 10 pC (~ 5 pe)
- low efficiency for the small charge due to the quantum and collection efficiency



Super Nova rate test

- emulating SN burst time profile (~ 10 s) with a laser diode
- ~ 60 M hit in 10s $>$ of a possible nearby supernova (Betelgeuse)
- digitizer hit rate increased up to 1.3MHz per channel without error.
- SK electronic limit is 500 KHz
- total recorded hits/ch reach 3.6M hits in 10s





Summary

- We presented the developed HK frontend electronics
- the mass production will start in few months.
- We did tests in lab and using the Super Kamiokande experiment for a realistic environment
- HK Elec. worked as expected and observed neutrino events for the first time.
- The performance comply with the requirements