Integration of Hyper-Kamiokande Electronics and Test in Super-Kamiokande

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for the Hyper-Kamiokande Collaboration

Hyper-Kamiokande

- **Next generation neutrino experiment starts in 2027**
  - ✓ 260kton water tank (FV=190kton) *.. ~8 times larger than SK*
  - ✓ 20'' HK Box&Line PMT (~20,000 PMTs)
    .. performance improved by a factor 2
    (detection efficiency, Q/T resolution)
  - ✓ also a part of long base line experiment

- **Rich physics programs**
  - ✓ Neutrino physics (Atmospheric, accelerator)
  - ✓ Proton decay
  - ✓ Astrophysics neutrino (Supernova, relic SN, Solar, etc)

20'' HK PMT
（R12860）

HK water tank

72m

68m

Solar neutrinos   Supernova ν   Atmospheric ν   Accelerator ν   Proton decay
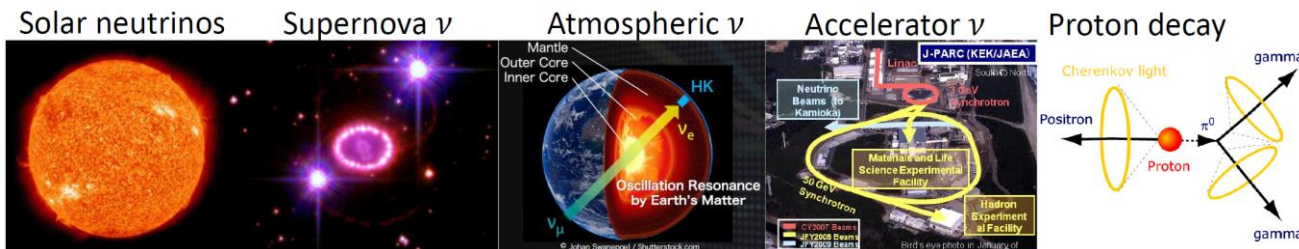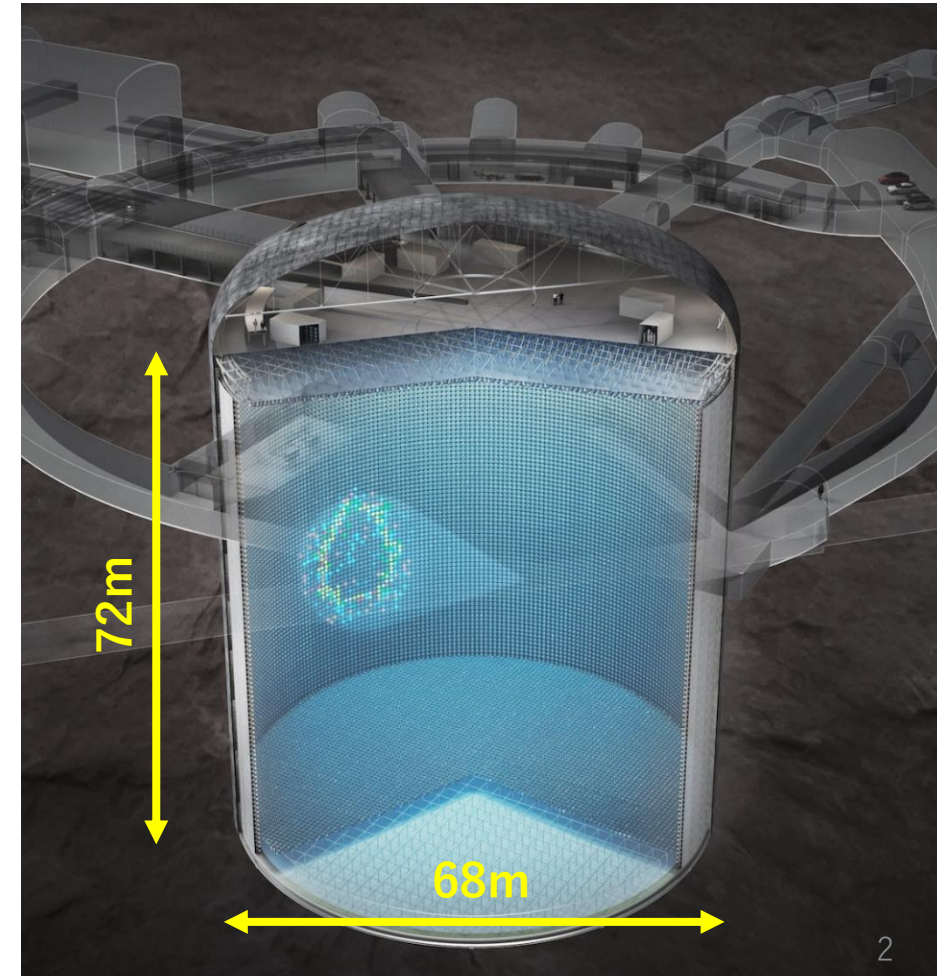
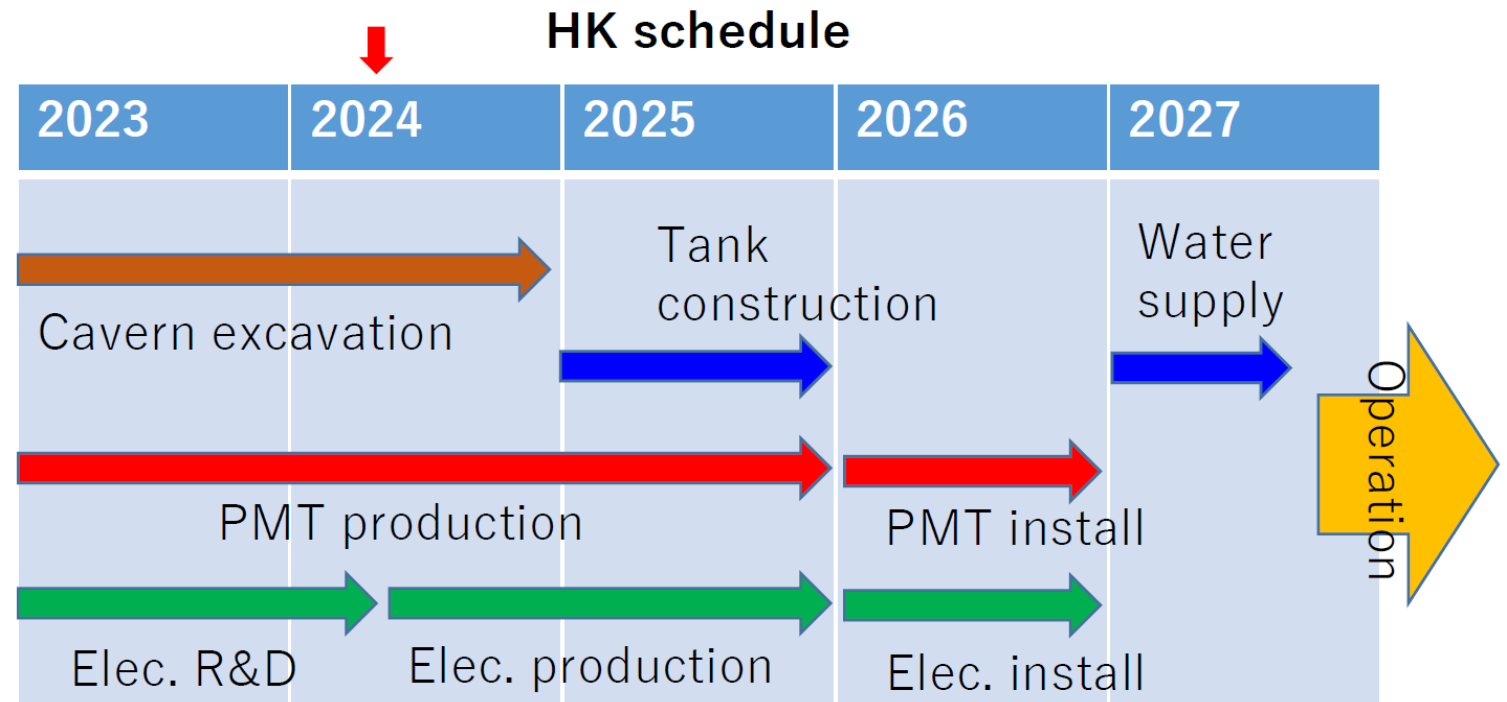# HK Construction Schedule

- **HK construction is on-going**

  ✓ main cavern is under excavation

  ✓ PMT mass production is on-going since 2020

  ✓ We are finalizing electronics design, and after final tests we move on mass production
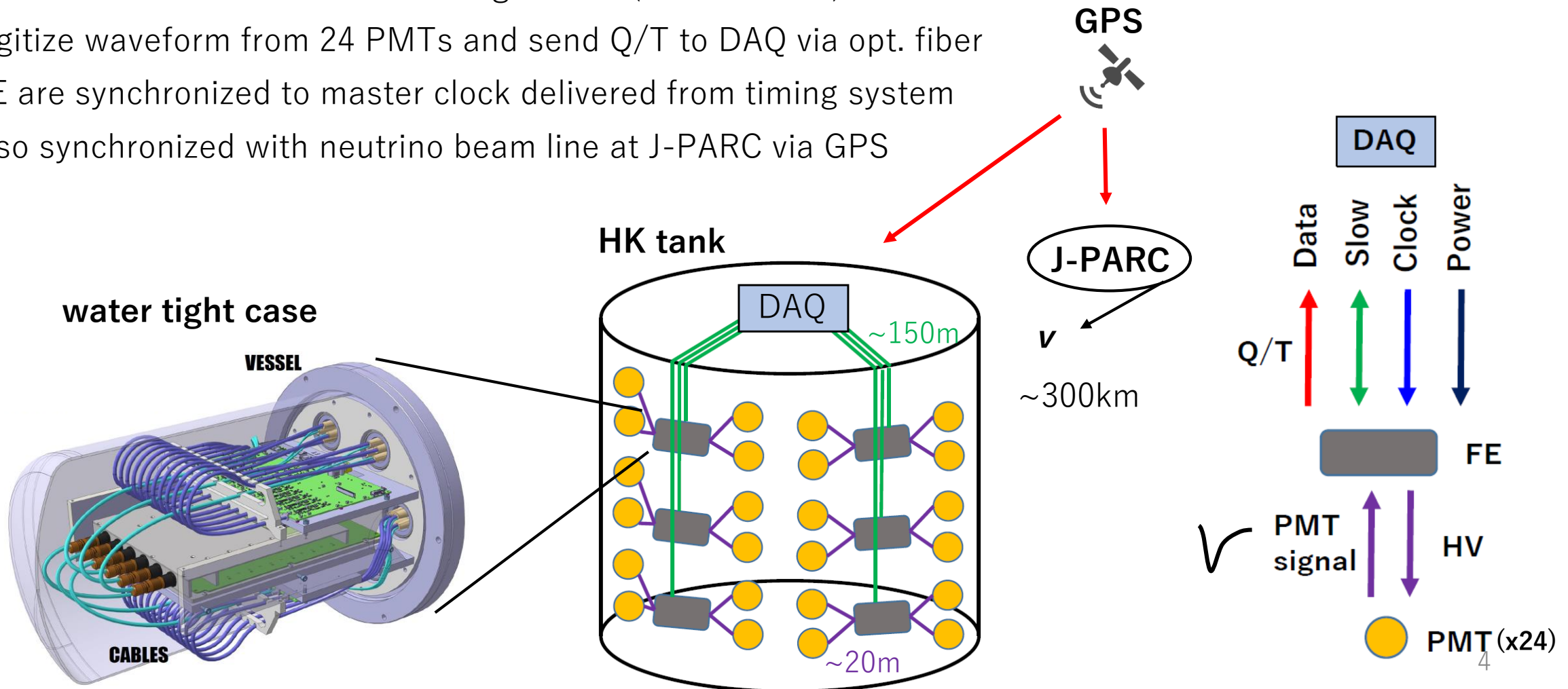
main cavern (under excavation)

PMT mass prod. (quality check)

HK schedule

2023	2024	2025	2026	2027
Cavern excavation		Tank construction		Water supply
PMT production			PMT install	Operation
Elec. R&D	Elec. production		Elec. install	

Concept of HK Electronics

- **Frontend electronics is placed under water inside HK tank** (↔ outside of tank in SK)

✓ install FE in 1MPa tolerant water tight case (~1000 cases)

✓ digitize waveform from 24 PMTs and send Q/T to DAQ via opt. fiber

✓ FE are synchronized to master clock delivered from timing system

✓ also synchronized with neutrino beam line at J-PARC via GPS

GPS

J-PARC

ν

~300km

HK tank

DAQ

~150m

~20m

water tight case

VESSEL

CABLES

DAQ

Data | Slow | Clock | Power

Q/T

FE

PMT signal

HV

PMT (x24)

4

HK Elec. Requirements

- Rich physics programs require <u>wide range in energy and event rate</u>
- High performance HK PMT requires <u>high resolution in charge and timing</u>
- Underwater environment sets <u>additional constraints</u> (water-tight, heat control, failure rate, etc)
- → <u>HK Elec. is requested to have equal or better performance than SK Elec.</u>

HK requirements

Items	Requirements	
single photon detection	Thr.<1/6pe	1pe~2pC~6mV
Deadtime, rate tolerance	**<500ns, 2MHz**	for μ decay e, neutron, SN burst
Charge resolution	**<10%@1pe**	PMT~30%@1pe
Timing resolution	**<300ps@1pe**	PMT~1ns@1pe
Charge range, linearity	**~1250pe, <1%**	MeV~100GeV event
Temperature dependence	<0.1%/°C	with on-board calibrator
Synchronization	<100ps	for chrenkov ring reconstruction
Buffer & Through-put	O(GB), 1Gbps	for SN burst ~200M events in 10s
10 years operation under water	**failure rate<1%/yr discharge tolerance**	water-tight, heat control, full remote, etc

difference to SK Elec.

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

5

Frontend Boards

- FE consists of some boards, and <u>prototypes are all ready</u>.

Digitizer board (12ch) x 2
- ✓ digitize PMT waveform to Q/T
- ✓ made by discrete analog components
- ✓ integrator & FADC
- ✓ FPGA TDC

Data Process board
- ✓ process digitizer hits
  and communicate to DAQ with 1Gbps links
- ✓ slow control
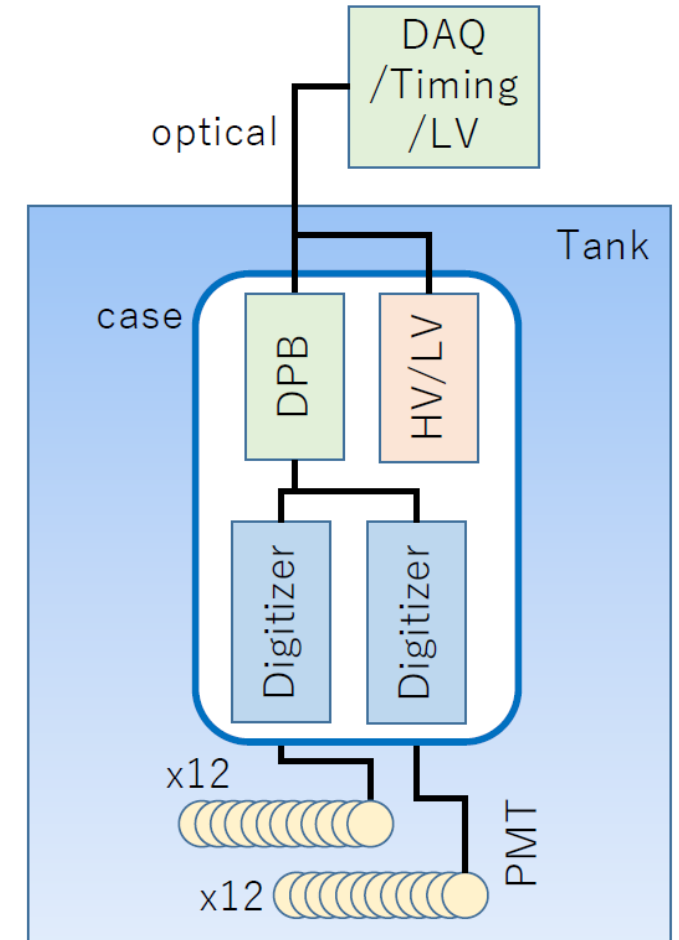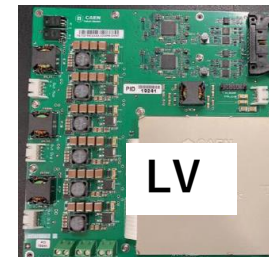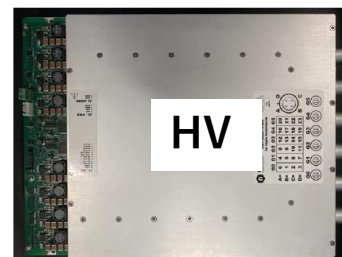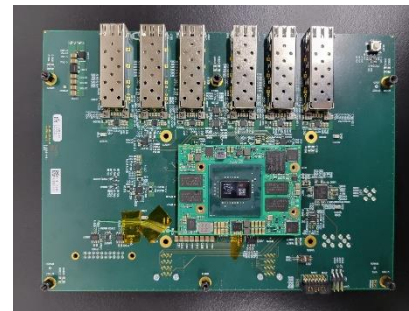- ✓ timing distribution

HV/LV board
- ✓ 48V input (2A) <100W
- ✓ HV ~2.5kV for 24 PMTs
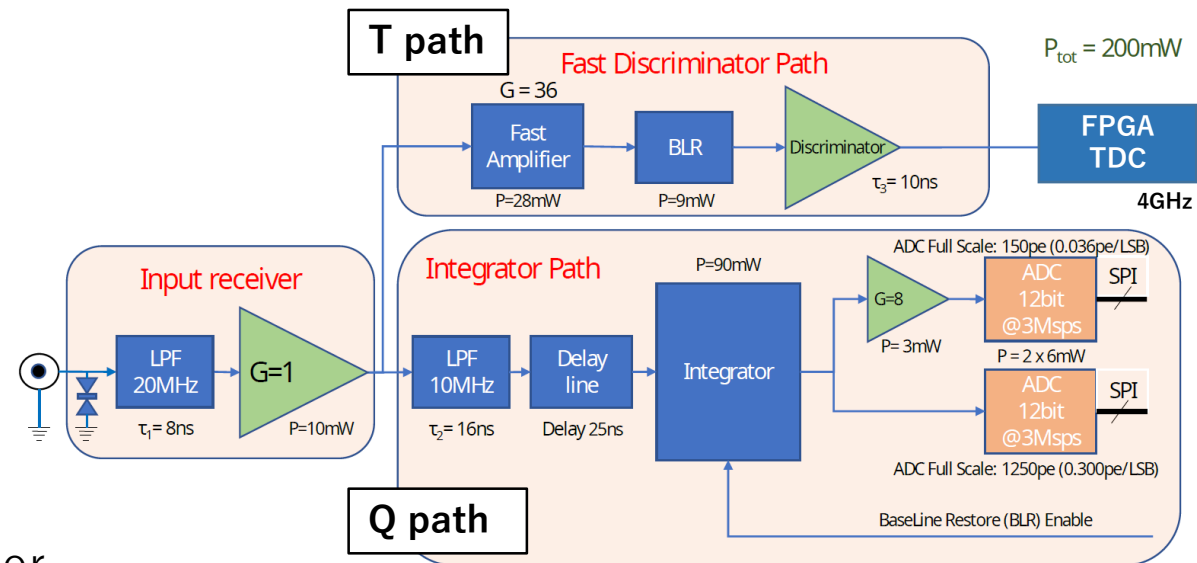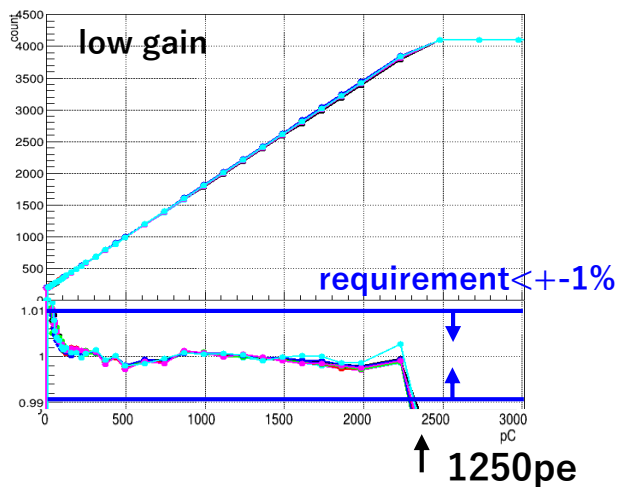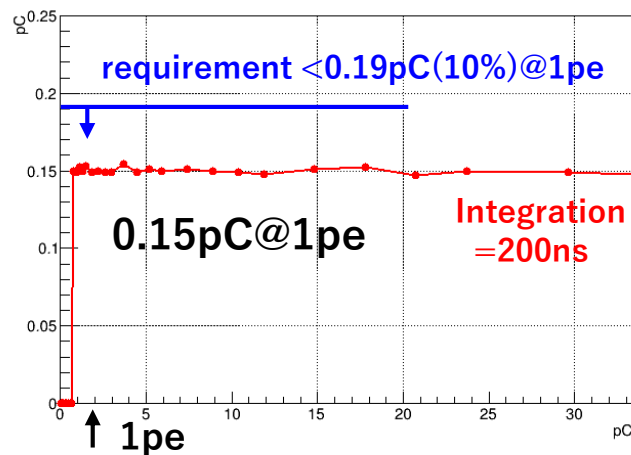
HK digitizer board

DPB

HK Digitizer

- Discrete design (non-ASIC) with Q/T paths
- ✓ **Q path:** Integrator and FADC,

  2 ranges to cover 2350pC with 1% linearity
- ✓ **T path:** Discriminator and FPGA TDC

  multi phase TDC: 500MHz x 8 phases ~ 4GHz
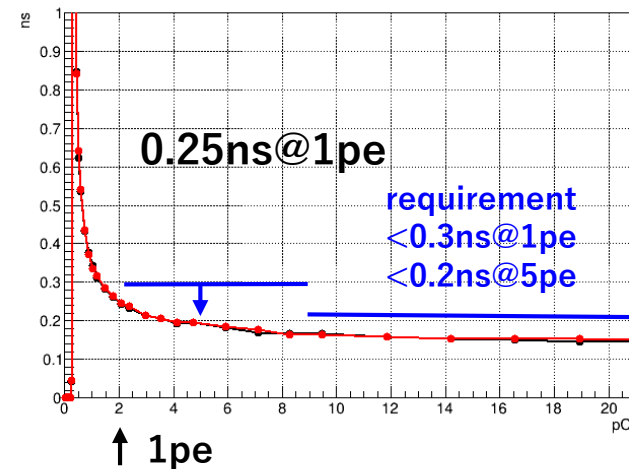
- confirmed to meet requirements by pulse generator

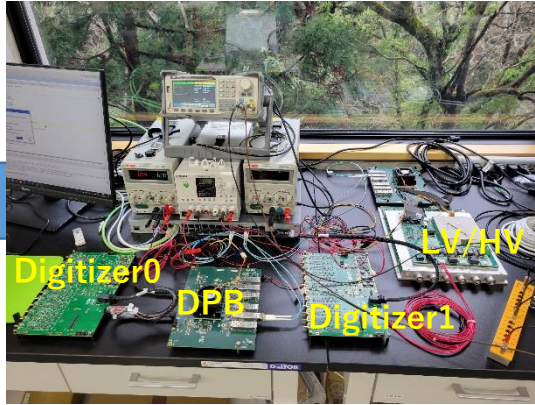**Charge Linearity**

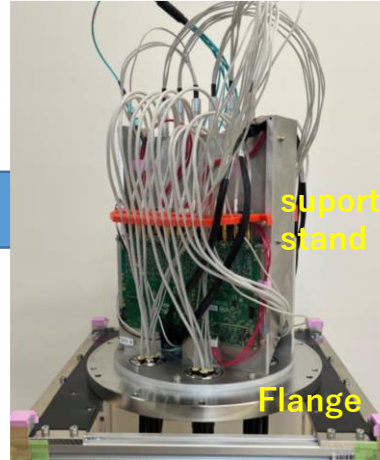**Charge resolution**

Time resolution

Integration and Tests
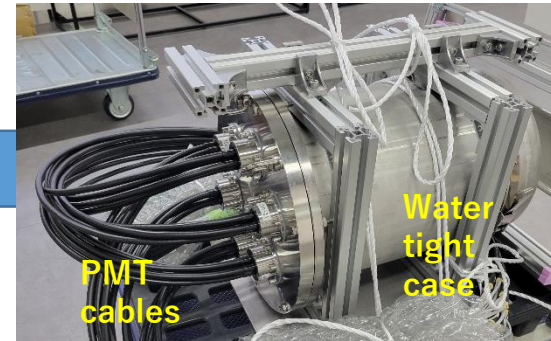
- FE prototype boards have been integrated to work as a system

Integration of boards

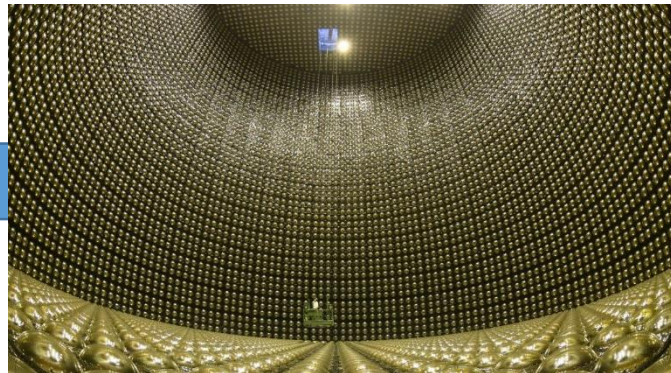**Mounting on stand**

Installed in water tight case

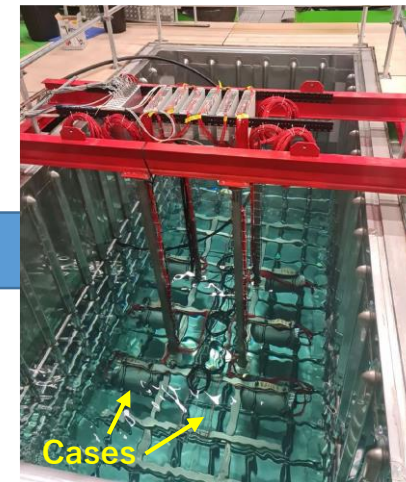- Tests in realistic environment is on going

Test with HK PMT

focus of this talk

Test with SK
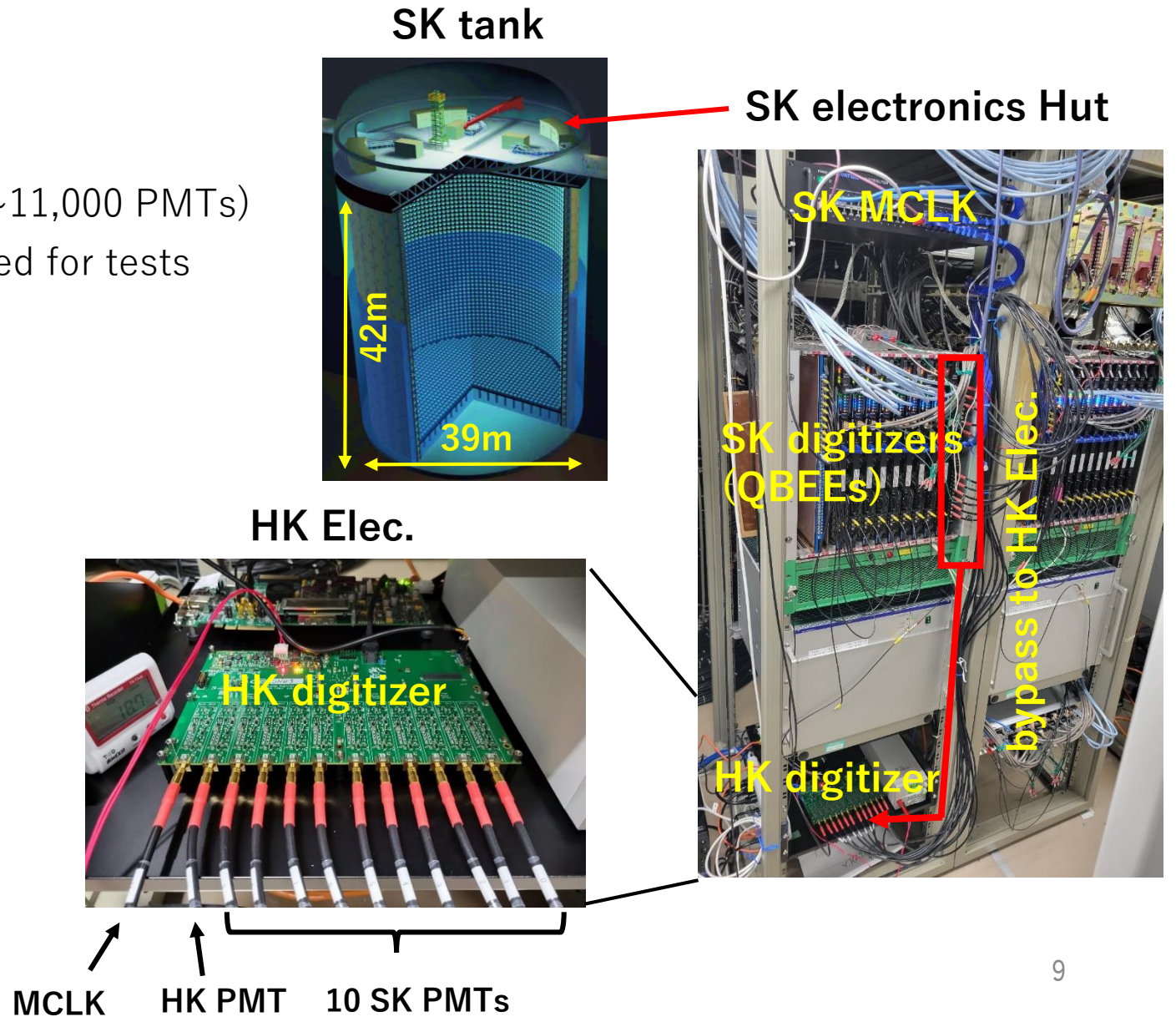

Under water test

ready to production

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. (QBEE)

- **Setup**
  ✓ FE is in electronics hut outside of SK tank
  ✓ starts from single HK digitizer board
    (move on full setup in the near future)
  ✓ replace 1 SK board (/500) with HK board
  ✓ connected to **10 SK PMTs, 1 HK PMT,**
    also SK master clock to synchronize

SK tank

42m
39m

SK electronics Hut

SK MCLK

SK digitizers (QBEEs)

bypass to HK Elec.

HK digitizer

HK Elec.

HK digitizer

MCLK   HK PMT   10 SK PMTs

Single photon detection
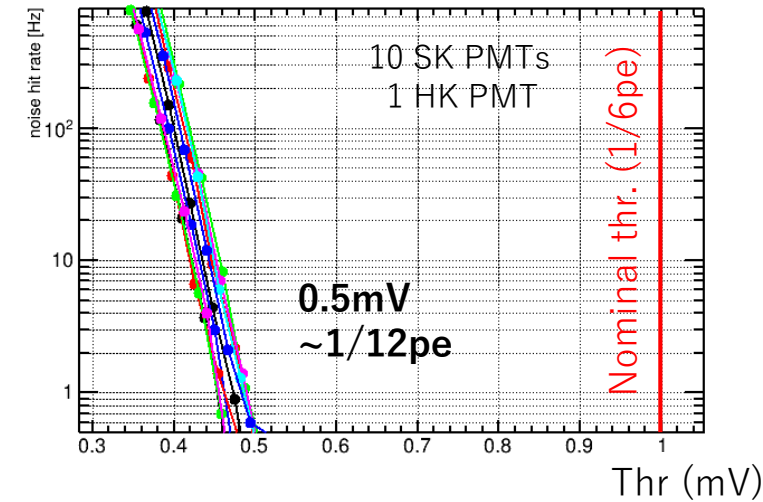
Noise hit rate

- **Noise level**

✓ Noise level confirmed to be <u>0.5mV ~ 1/12pe</u> (<requirement 1/6pe)

- **Charge measurement (by dark hits)**

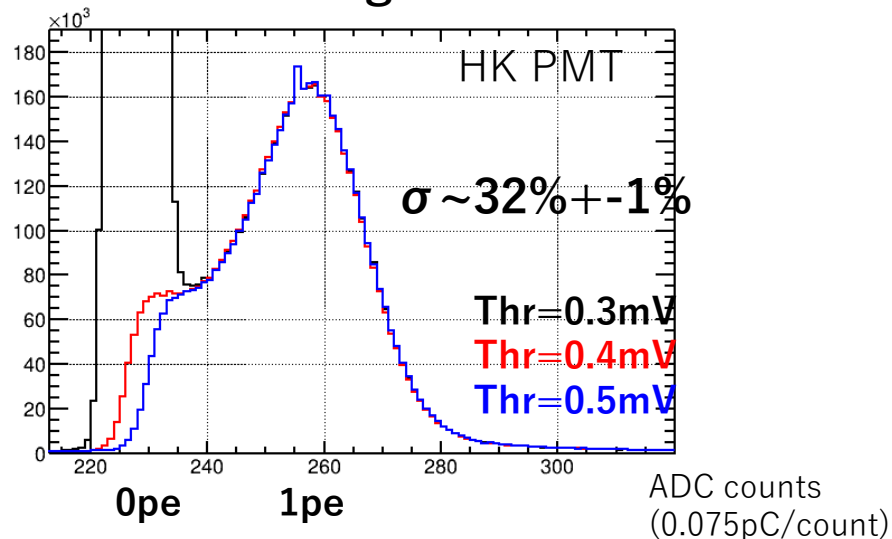✓ observed good resolution of <u>HK PMT ~ 32% @ 1pe</u> (SK PMT ~ 50%)

✓ no difference with SK electronics (resolution of electronics ~ 10% @ 1pe)

10 SK PMTs
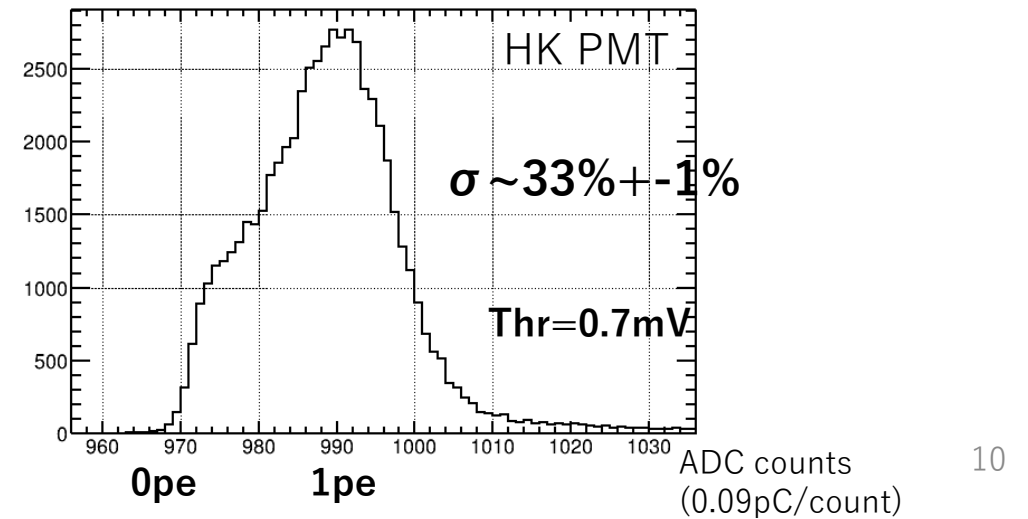1 HK PMT

Nominal thr. (1/6pe)

0.5mV
~1/12pe

Thr (mV)

HK Elec.

Charge

HK PMT

σ~32%+-1%

Thr=0.3mV
Thr=0.4mV
Thr=0.5mV

0pe   1pe

ADC counts
(0.075pC/count)

SK Elec.

Charge

HK PMT

σ~33%+-1%

Thr=0.7mV

0pe   1pe

ADC counts
(0.09pC/count)

Timing performance

0.04Hz
~10pe /PMT

SK tank

TQ Laser
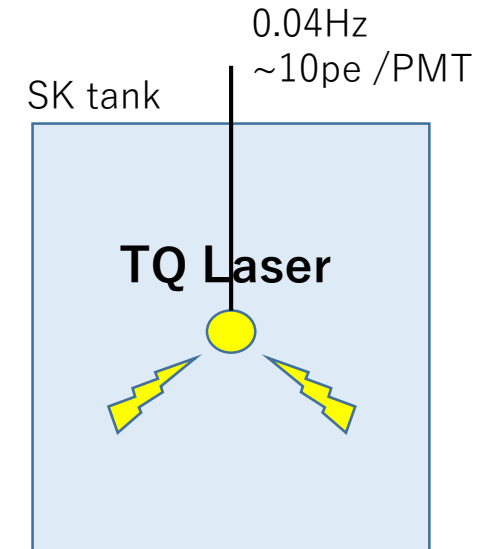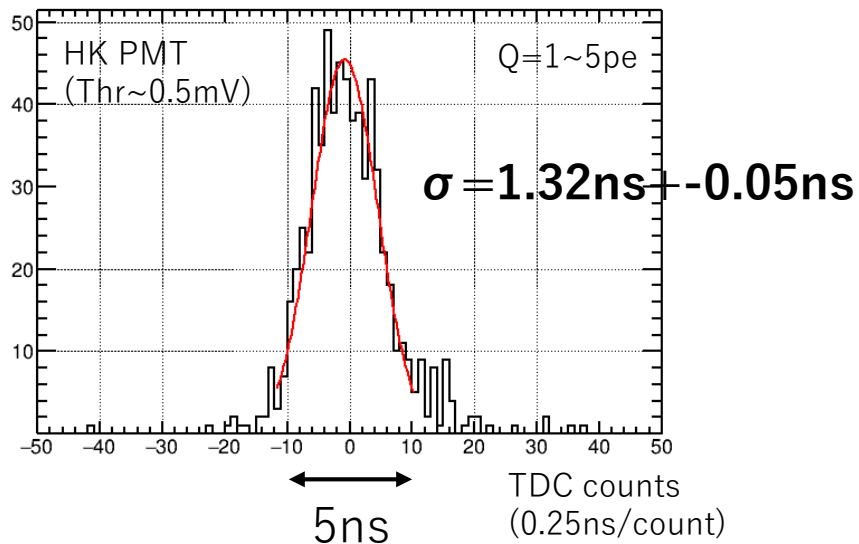
- **Timing measurement (by laser)**

✓ make use of calibration laser source in SK tank

✓ observed good resolution of <u>HK PMT ~ 1.3ns</u> (SK PMT ~ 2ns)

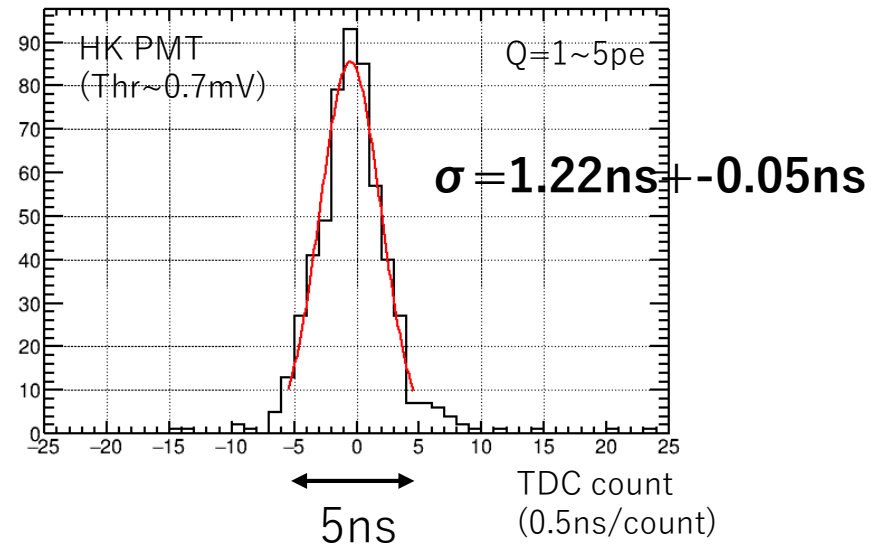✓ no difference with SK electronics (resolution of electronics ~0.2ns)

HK Elec.

Timing

HK PMT
(Thr~0.5mV)   Q=1~5pe

σ＝1.32ns+-0.05ns

TDC counts
(0.25ns/count)

5ns

SK Elec.

Timing

HK PMT
(Thr~0.7mV)   Q=1~5pe

σ＝1.22ns+-0.05ns
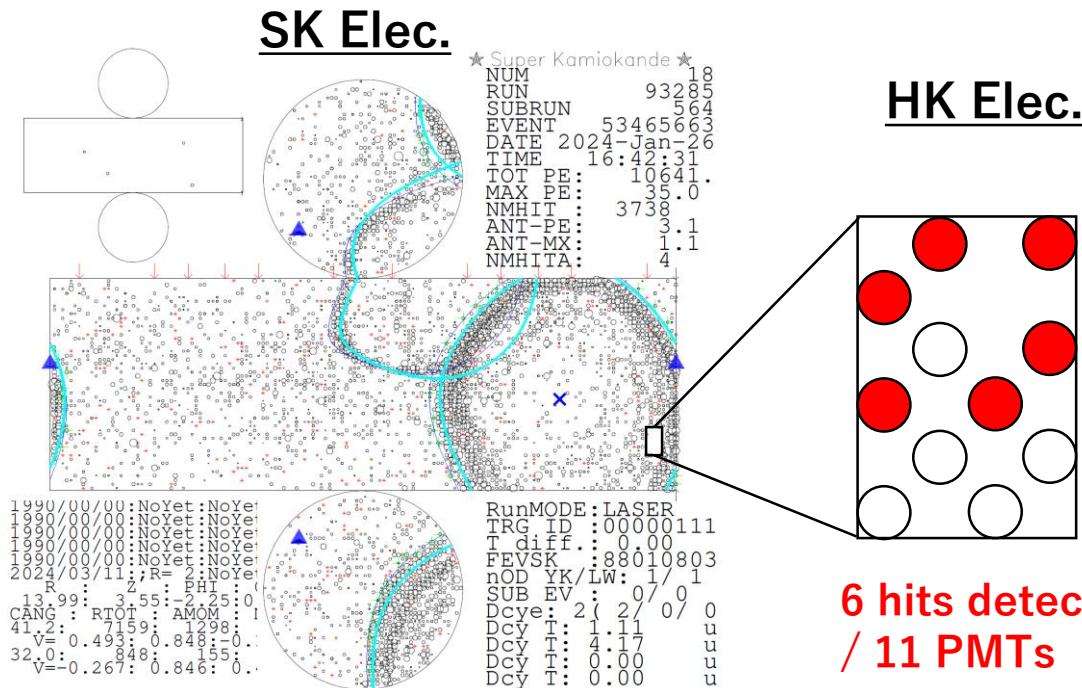
TDC count
(0.5ns/count)

5ns

Neutrino events

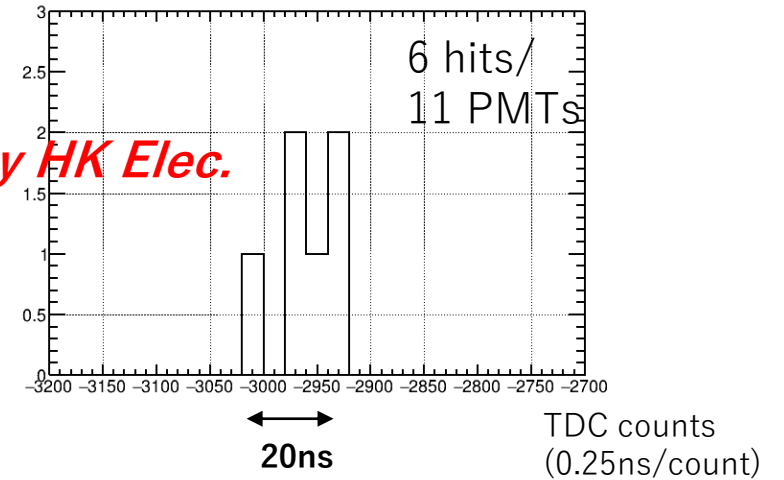## First observation of Neutrino signal events

- neutrino events selected by SK Elec. data.
  → observed coincidence hits in HK elec.

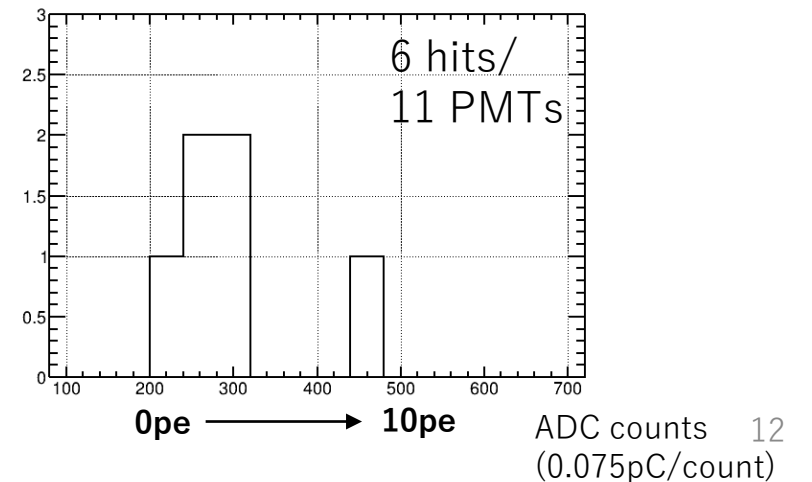 *First observation of Neutrino event by HK Elec.*

- An example of neutrino event

SK Elec.

HK Elec.

6 hits detected / 11 PMTs

Timing

6 hits/ 11 PMTs

20ns

TDC counts (0.25ns/count)

Charge

6 hits/ 11 PMTs

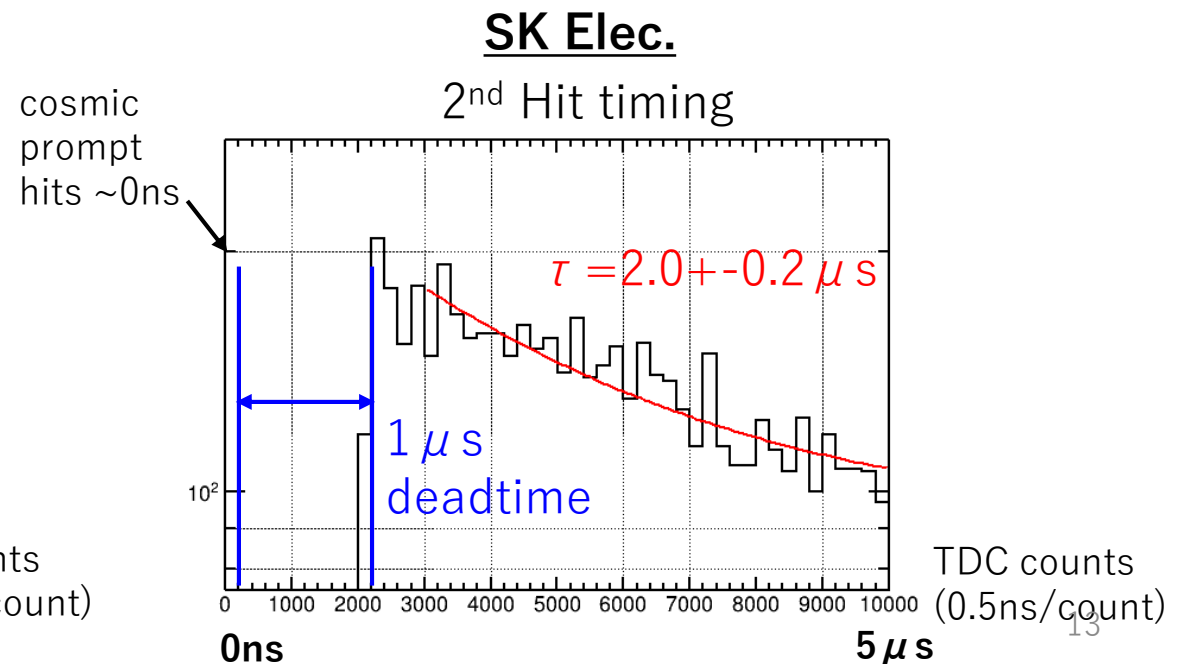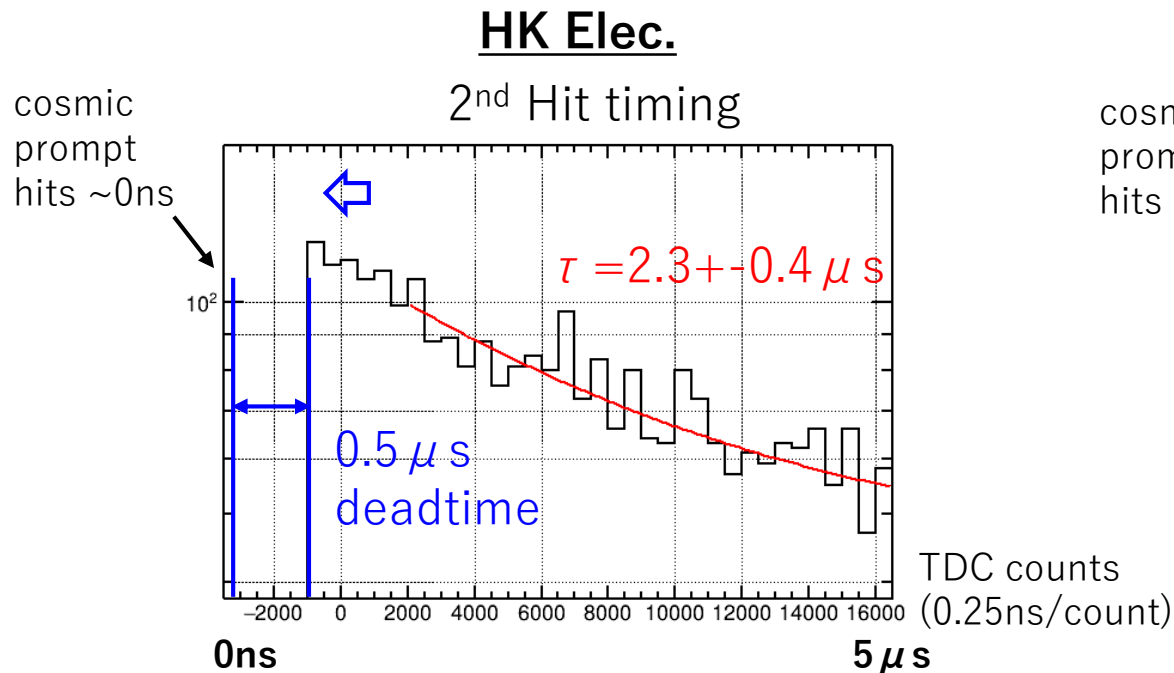0pe ⟶ 10pe

ADC counts (0.075pC/count)

Consecutive hits

- **Consecutive hits in short period**

  ✓ important to detect μ decay, neutron capture, supernova burst, etc
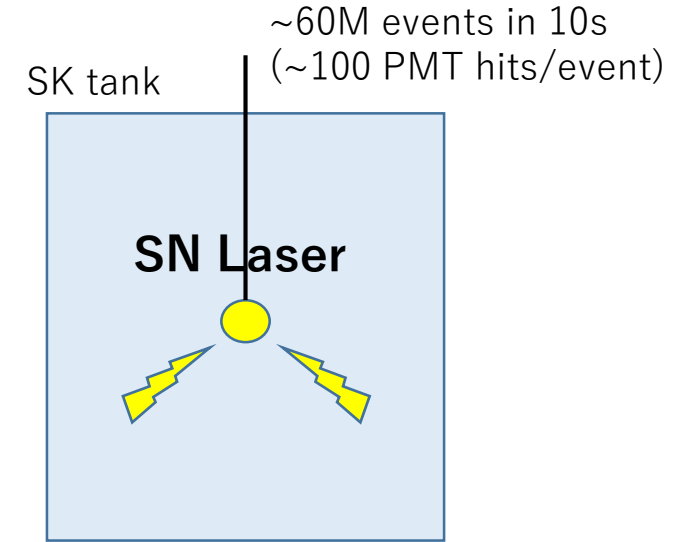
- **μ decay in cosmic events**

  ✓ confirmed to detect μ decay e hits up to 0.5μs(deadtime) in HK Elec.,

  improved from 1.0μs(deadtime) in SK Elec.

SN burst test

~60M events in 10s
(~100 PMT hits/event)

SK tank

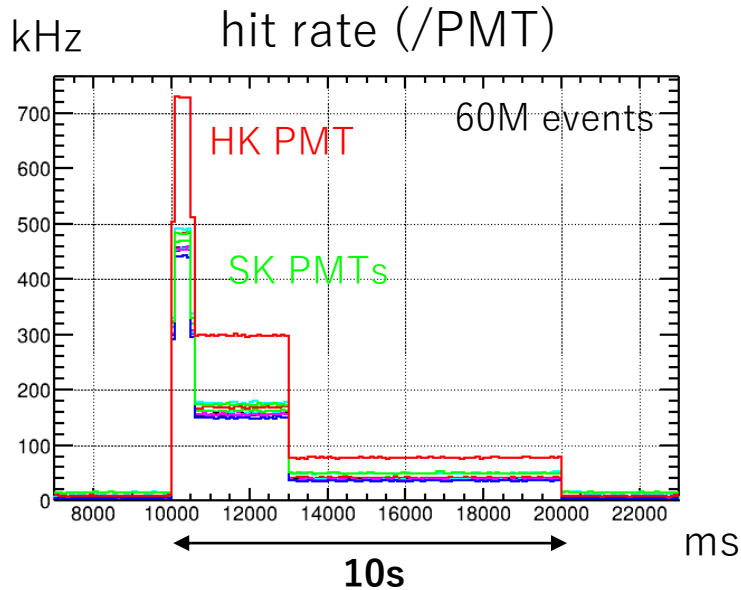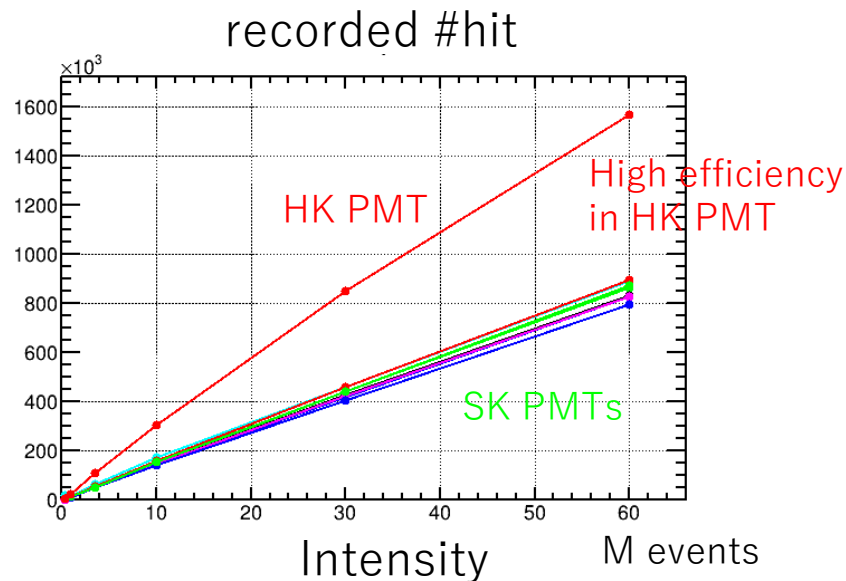**SN Laser**

- **SN burst test by laser**

✓ emulating SN burst time profile (~10s)

✓ intensity up to 60M events > nearby supernova (betelgeuse)

✓ confirmed to <u>process ~700kHz /channel without error</u>

✓ confirmed to <u>record all 1.6M hits /10s</u>

(in SK Elec., hits are presampled before buffer full)

HK Elec.

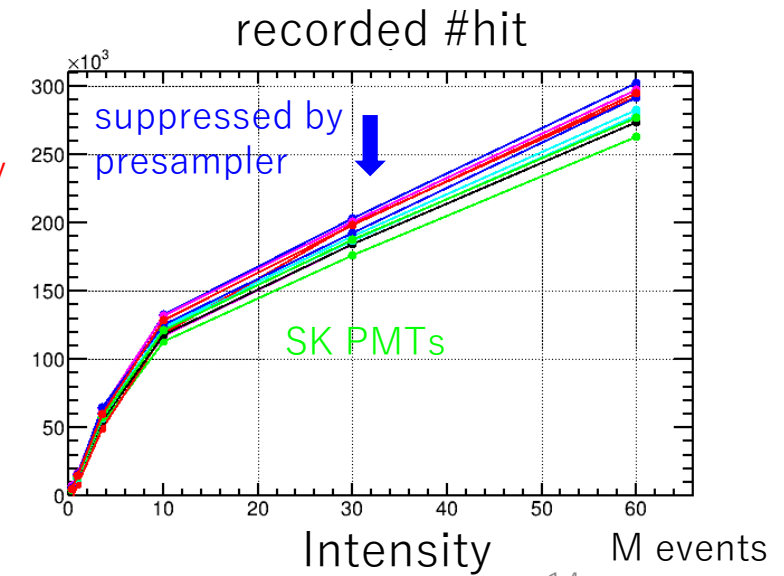kHz   hit rate (/PMT)

60M events

HK PMT

SK PMTs

10s

ms

HK Elec.

recorded #hit

HK PMT

High efficiency
in HK PMT

SK PMTs

Intensity   M events

SK Elec.

recorded #hit

suppressed by
presampler

SK PMTs

Intensity   M events

Summary

- We have developed HK frontend electronics
  and final tests are on-going before mass production.

- SK provides realistic environment for the final tests.

- HK Elec. worked in SK as expected and observed neutrino events for the first time.
  (compatible to SK Elec. and improved in some points, deadtime, high rate, etc)

- We are preparing test with full setup of HK Elec. in SK.
  (including data process board, timing system, LV/HV, etc)