Preparation of large aperture Photo-Detectors for the Hyper-Kamiokande

Takuya Tashiro (ICRR)
on behalf of Hyper-Kamiokande proto-collaboration

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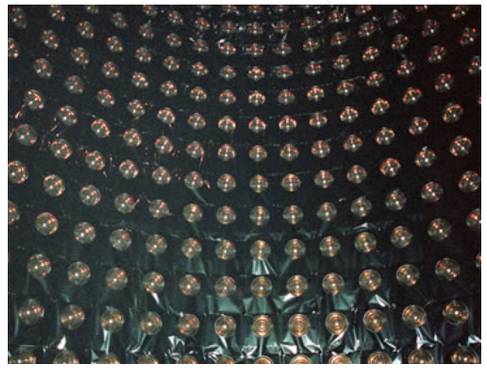
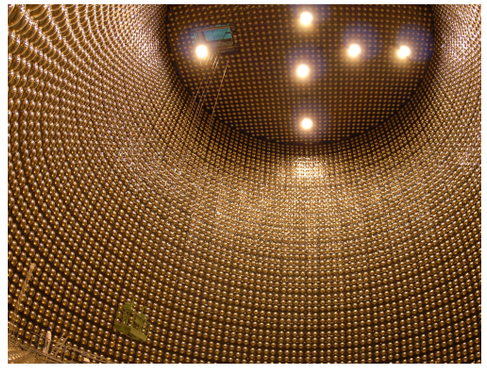
Hyper-Kamiokande(HK) experiment

HK is the **3rd generation water Cherenkov detector** in Kamioka, Japan.

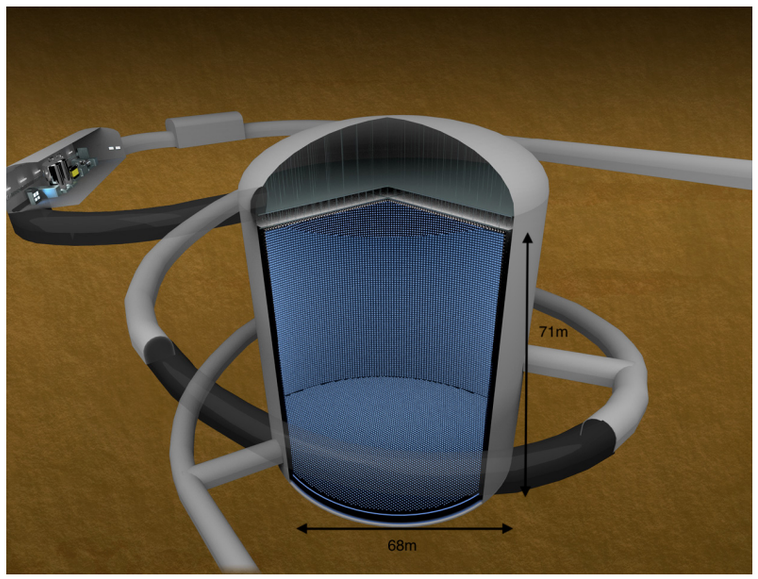
- 1st: Kamiokande(1983~1996)
  - Total mass: 3 kton, fiducial: 2.1 kton
  - Detected SN neutrinos.



- 2nd: Super-Kamiokande(1996~)
  - Total mass: 50 kton, Fiducial: 22.5 kton
  - Discovered neutrino oscillation.

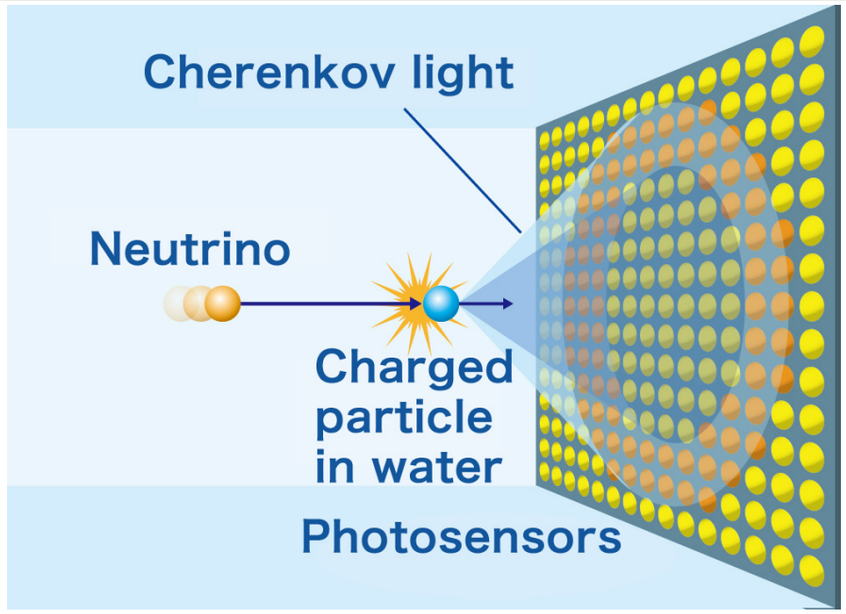


- 3rd: Hyper-Kamiokande(2027~)
  - Total mass: 260 kton, Fiducial: 188 kton
  - Designed to study several physics topics.
    - Nucleon-decay
    - CP violation in lepton sector
    - Neutrino astronomy
  - **Construction starts this year!**



Water-Cherenkov detector

- Charged particles passing through the water are identified using the Cherenkov-light detected by the photo-detectors attached to the wall.



- PID is performed based on the pattern of rings.

Showering ring
e-like

HK simulation

Non-showering
μ-like

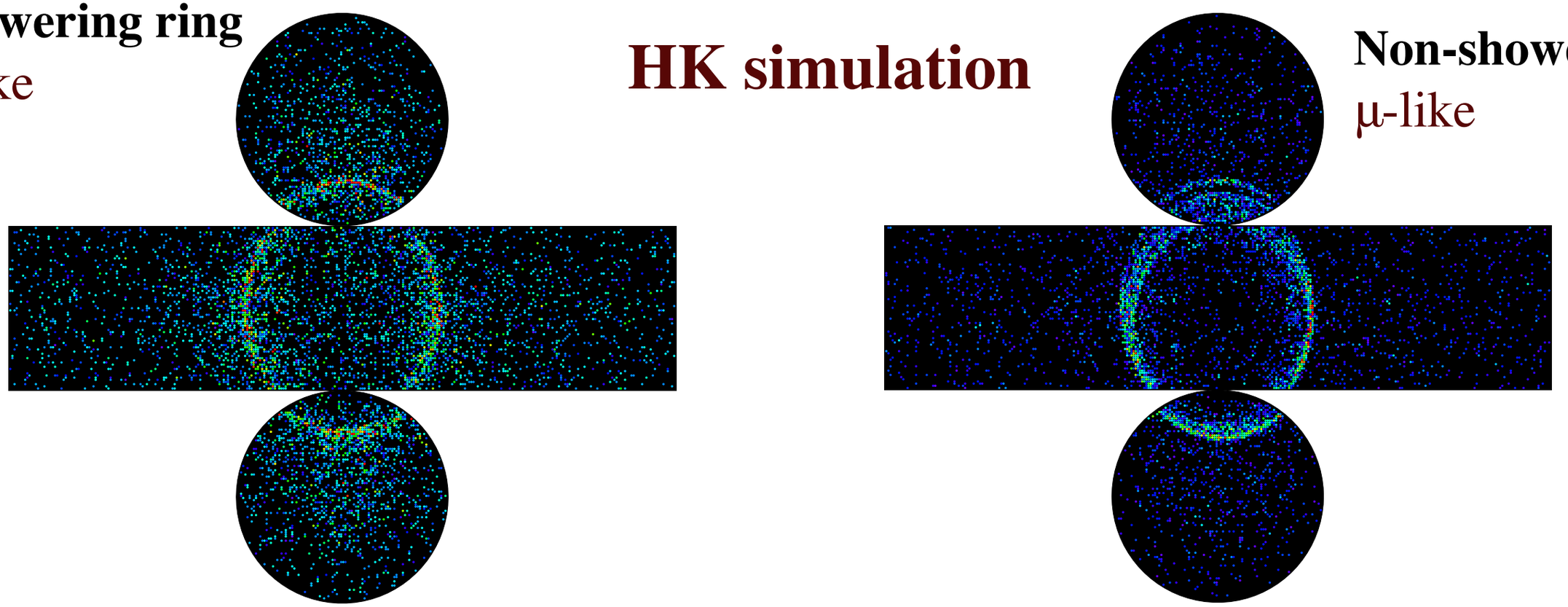


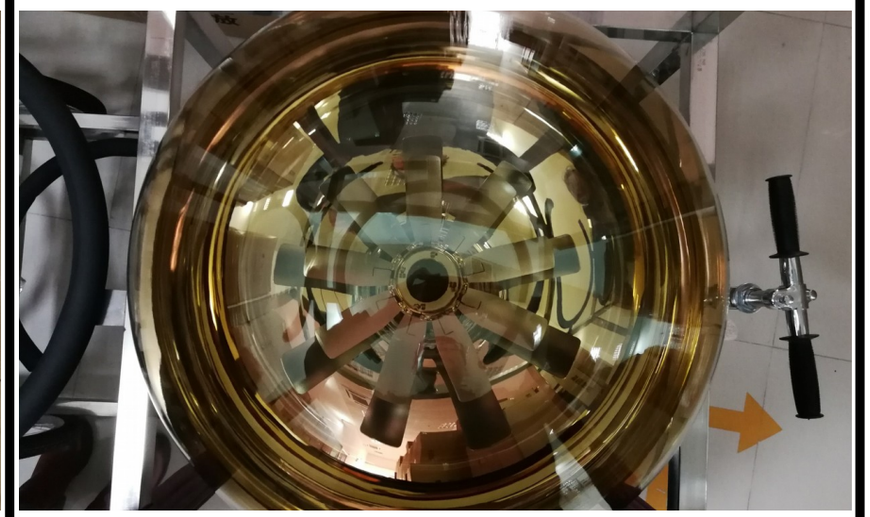
Photo-Detectors for HK inner tank

- Large-aperture photomultiplier tubes(PMTs) are used in HK.
- Several types of PMTs are considered.

Box&Line PMT

- Diameter of 20”
- ~100PMTs were Installed in SK to evaluate the performance.

MCP PMT



- Diameter of 20”
- Originally developed for JUNO
- Improvement has been studies to be suitable for HK

multi-PMT

- Multiple 3” PMTs are stored in a 20” case.
- Discussed in a dedicated talk by Gianfranca today.

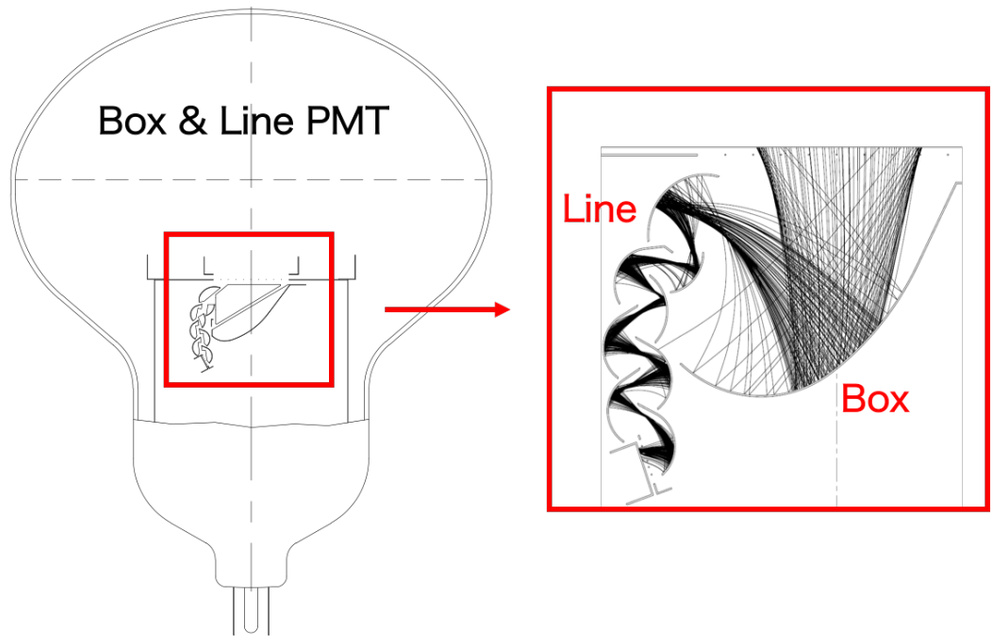
Mass production of 20” PMTs is scheduled to start this year

Preparation of 20” PMTs

- Preparation of 20” PMTs is ongoing for HK construction.
- Development of high quality PMTs:
  - High detection efficiency
  - Good charge and time resolution
  - Low dark noise rate
  - Tolerance to water pressure
- Evaluation of the performance
- Preparation of covers
  - Covers are required to be tolerant to HK water pressure and shock of PMT implosion.
- Development of support structure and installation method.

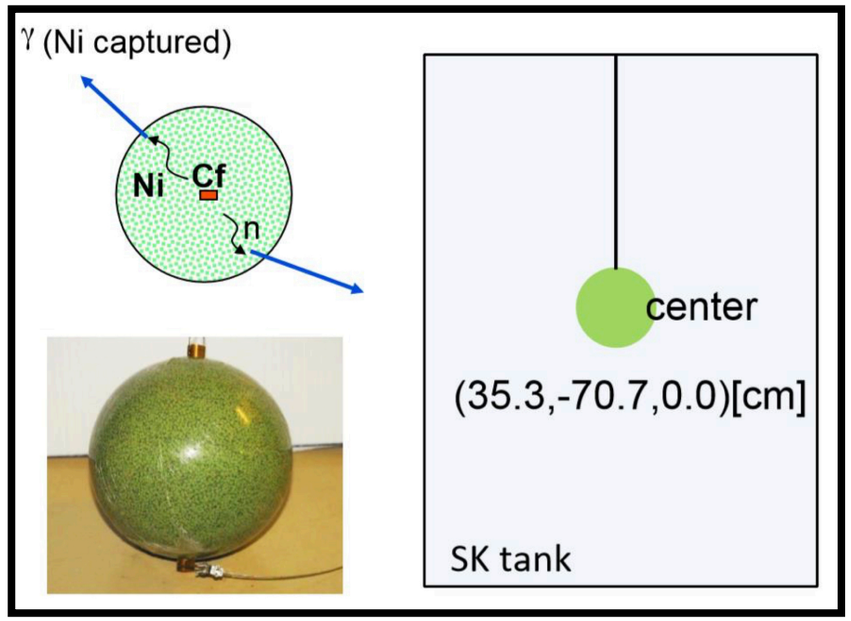
Box & Line PMT

- Box&Line(B&L) PMT was developed for HK by Hamamatsu photonics.
- Designed to have larger detection efficiency, time resolution, and charge resolution than SK PMTs.
- 136 B&L PMTs were installed into SK in 2018 to evaluate the performance in water.
  - Detection efficiency
  - Charge resolution
  - Time resolution



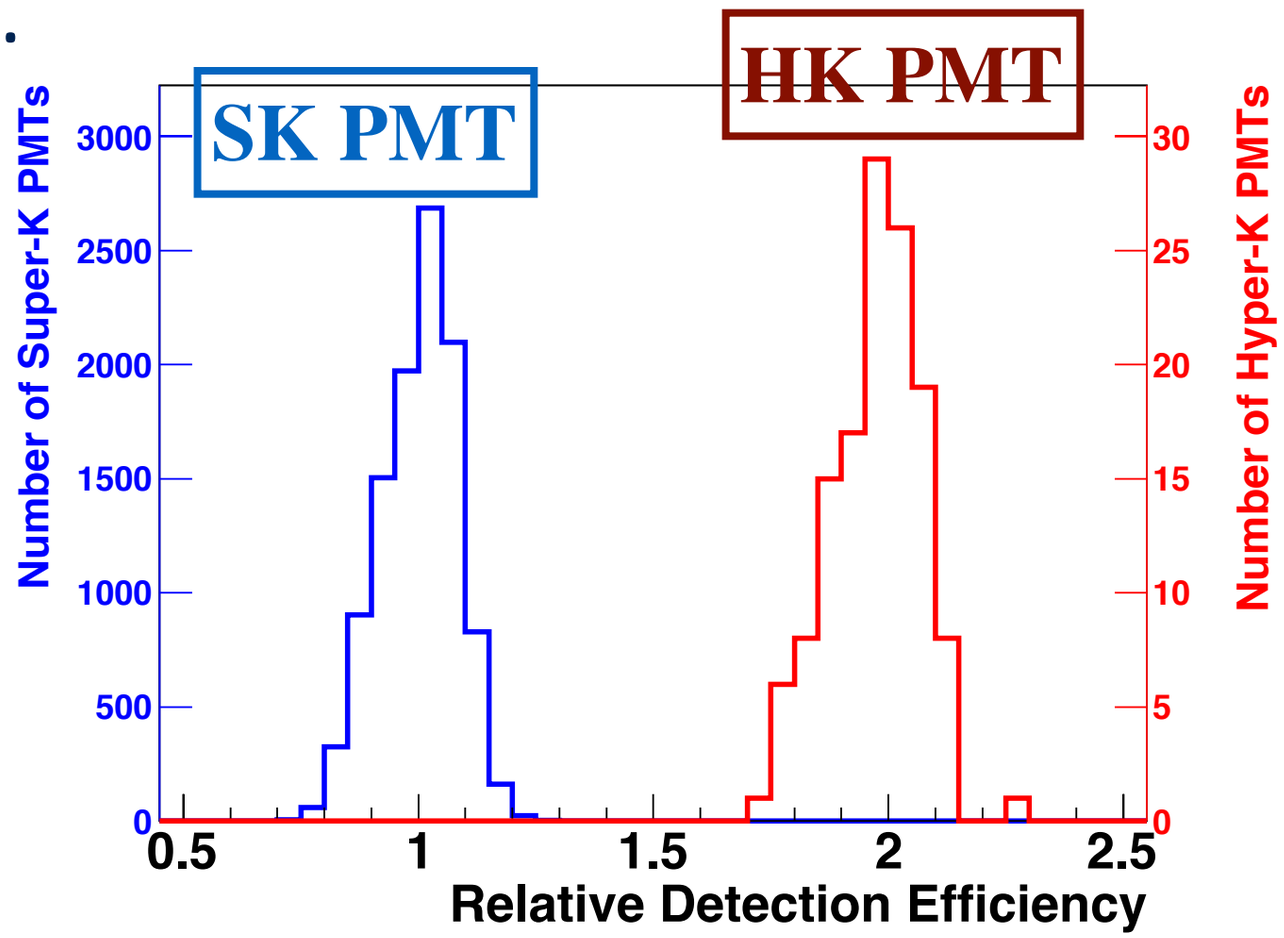
Box & Line PMT performance in SK

- **Detection efficiency** was measured using the calibration system of NiCf source.



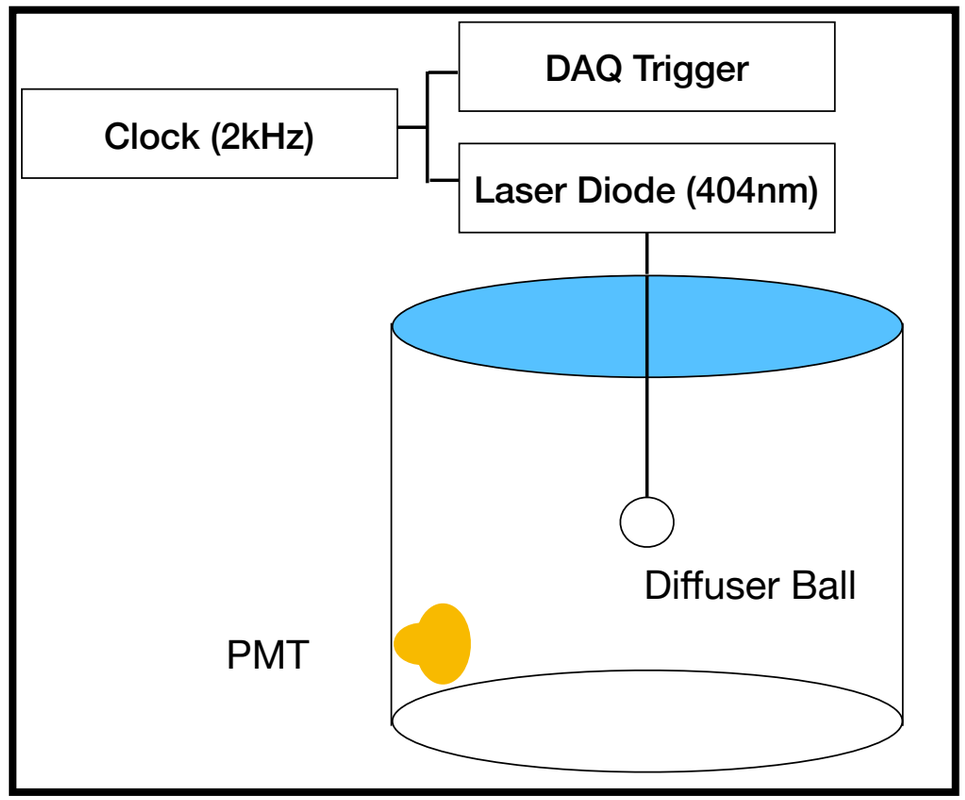
- The number of photons detected by a HK PMT is approximately **1.97 times** larger than a SK PMT in average.

- This improvement was achieved as a result of higher Quantum- and Collection- efficiency.

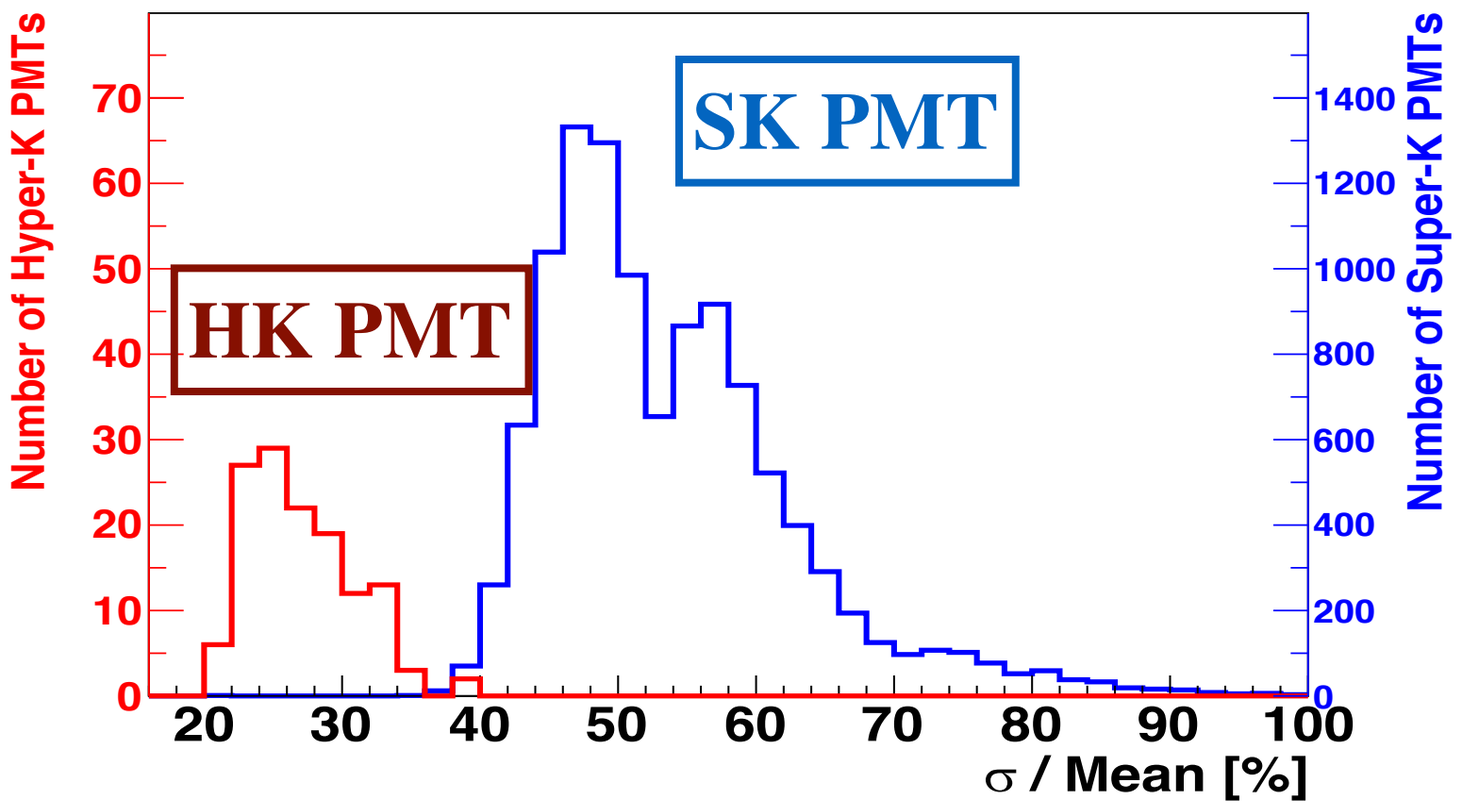


Box & Line PMT performance in SK

- **Charge resolution** was measured using the calibration system of laser diode.

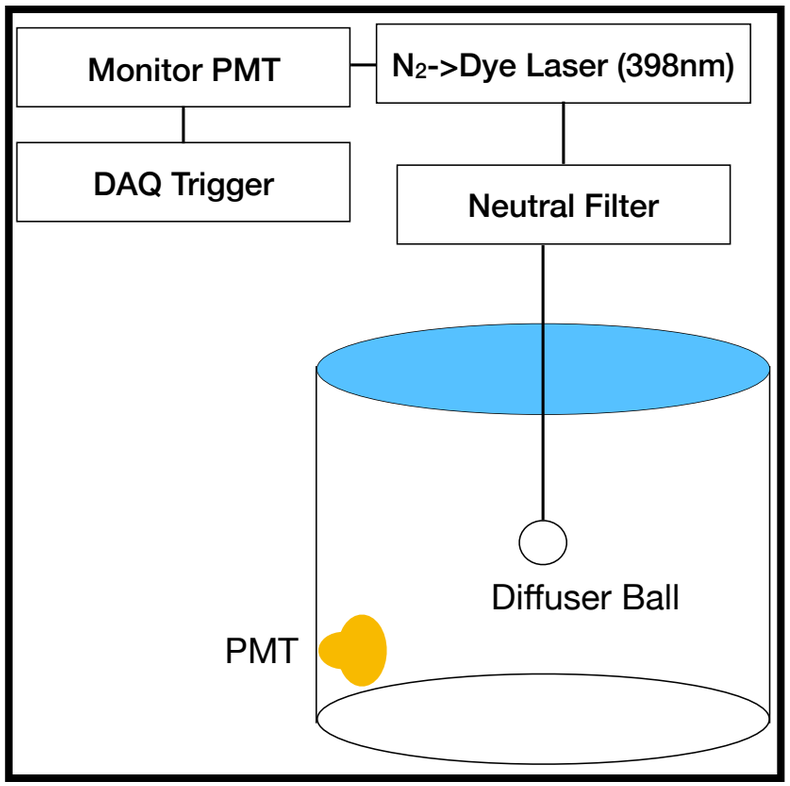


- The resolution of HK PMTs is about **twice better** than SK PMTs.
  - SK: σ/Mean~**54%**
  - HK: σ/Mean**~27%**

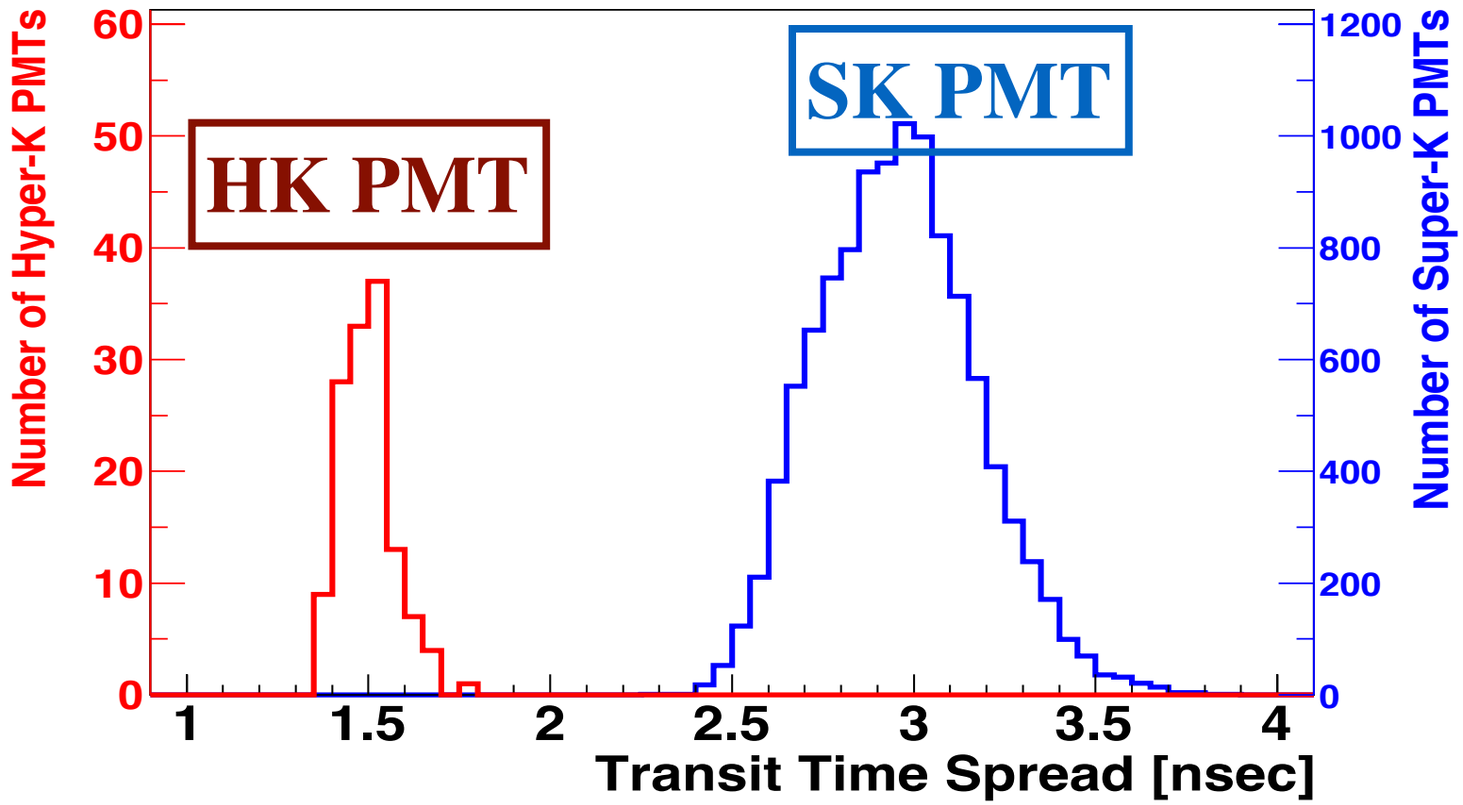


Box & Line PMT performance in SK

- **<u>Time resolution</u>** was measured using the calibration system of laser diode.

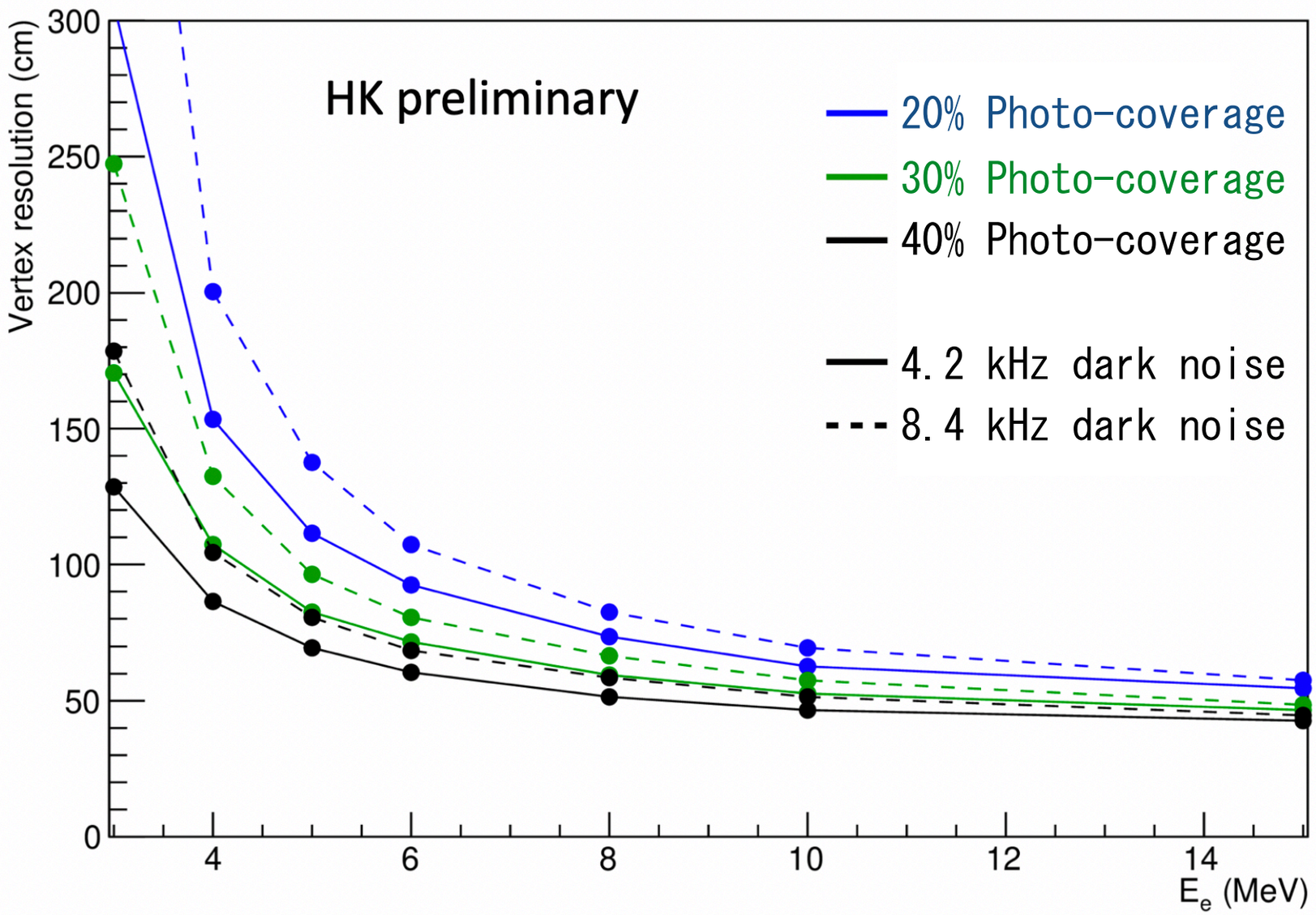


- The resolution of HK PMTs is about **twice better** than SK PMTs.
  - SK: TTS = **2.96 nsec**
  - HK: TTS = **1.50 nsec**



PMT dark noise

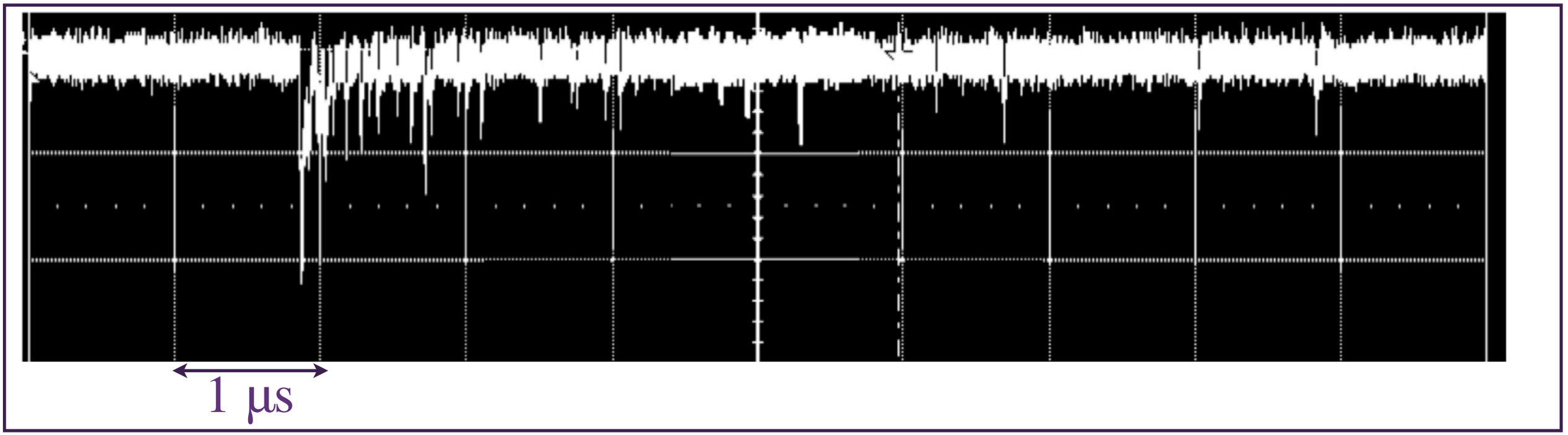
- Dark noise is one of the important properties of PMTs.
- The noise affects the reconstruction especially in low-energy events.



The goal of HK PMTs dark noise rate is 4 kHz.

Dark noise of B&L PMT

- Significant amount of dark noise is triggered by **continuous pulses**, the pulses that appear continuously within short time of *O*(10)μs.



- One of the sources of continuous pulses is scintillation light triggered by decay of radio-isotope(RI) contamination in the PMT bulbs.

We reduced the RI contamination to reduce dark noise.

Glass improvement

- The contamination of U and Th has been successfully reduced to ~1/2 in new glass.

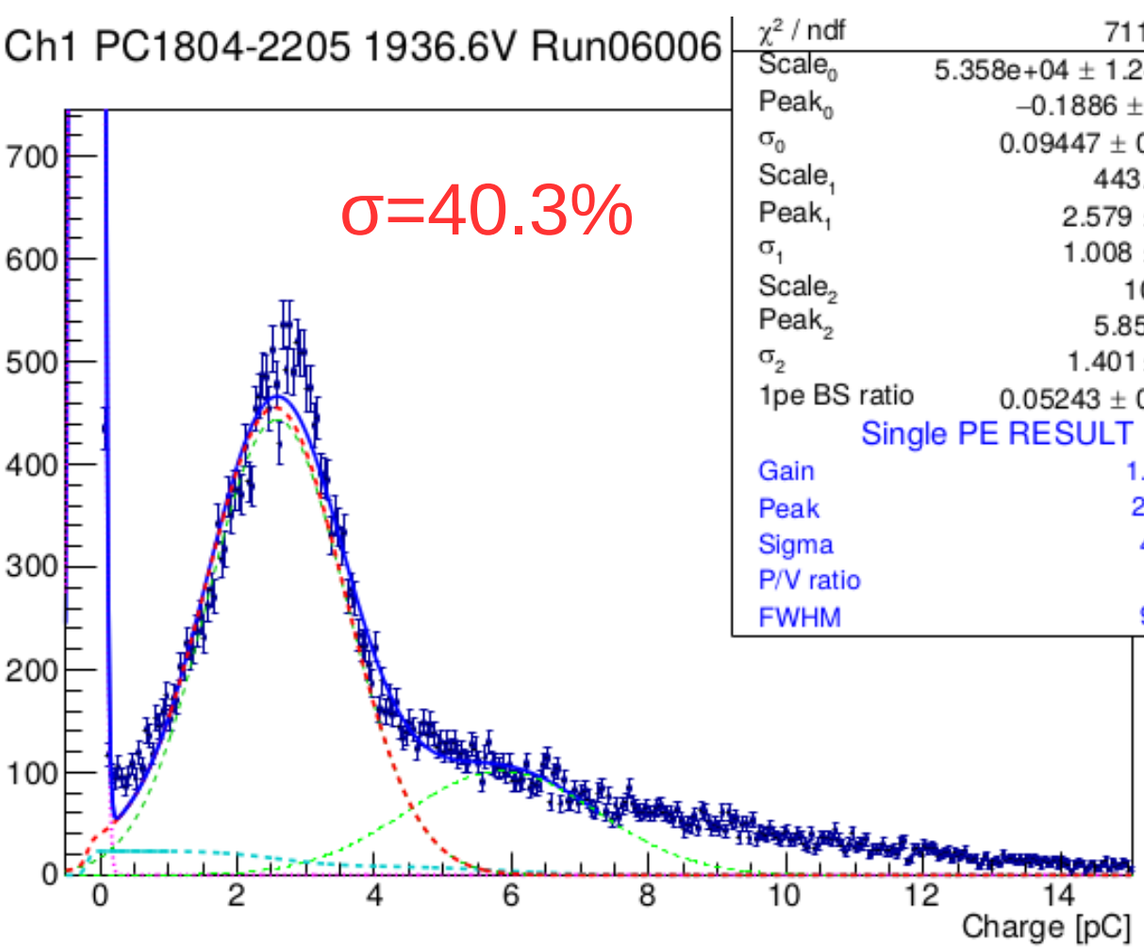
	SK PMT	HK PMT (Old)	HK PMT (New)
U [Bq/kg]	5.5	5.4	**2.9**
Th [Bq/kg]	1.8	1.8	**0.95**
^{40}K [Bq/kg]	18.2	1.6	**2.0**

- This improvement resulted in significant reduction of dark noise.
  - PMT with old glass: 6.6 kHz in average
  - **PMT with low-RI glass: as low as 4 kHz in average**

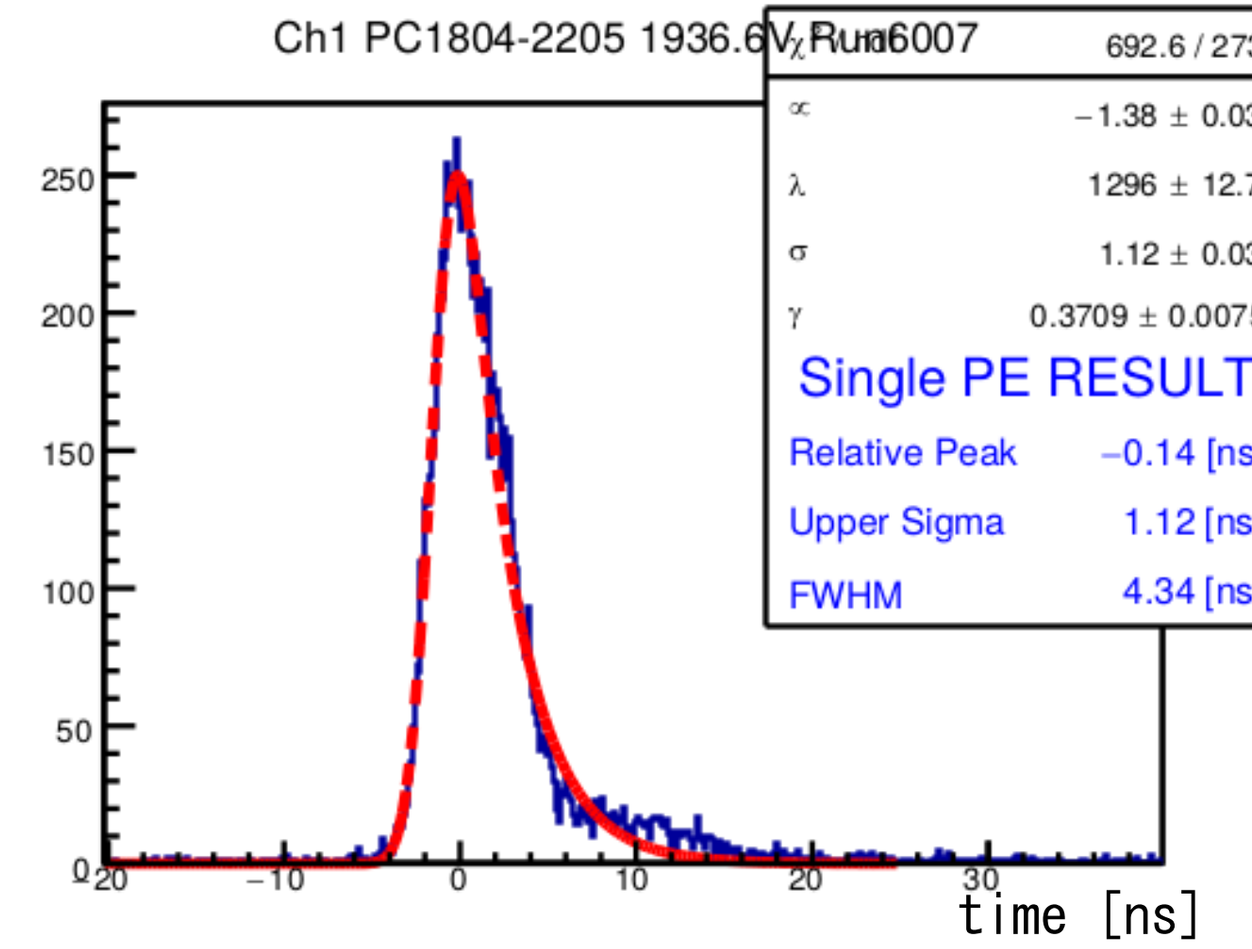
(Gate width: 1μs)

MCP PMT

- The performance was measured in Kamioka.



Counting resolution: **40.3%**

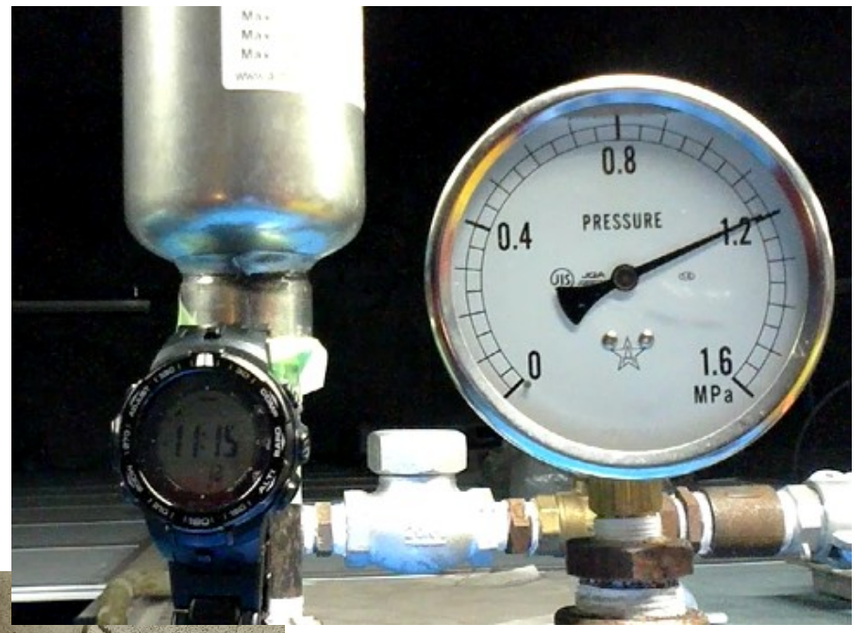


Time resolution:
1.8~1.9 ns (σ)

- Both counting and time resolution are better than SK PMT.
  - Charge resolution(SK PMT): 54%
  - Time resolution(SK PMT): 3.0 ns (σ)

MCP PMT

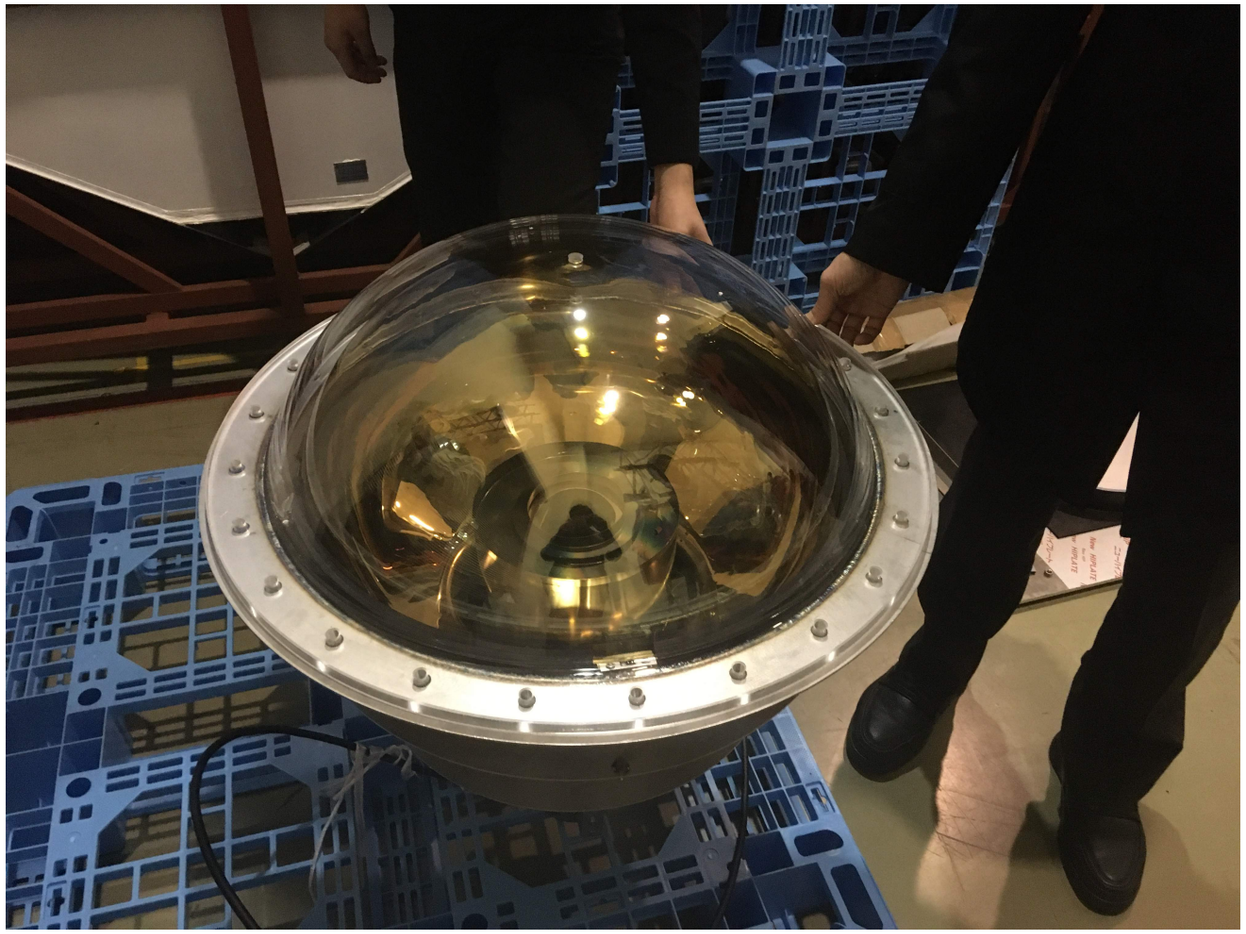
- Tolerance to water pressure was successfully proved.
  - The pressure of 1.2 MPa (corresponding to 120m water depth) did not damage the PMT.



PMT covers

- PMTs will be stored in covers to avoid chain implosion.
- Several designs are being prepared.

Implosion test is scheduled next year.



Implosion test is done.
Proved to work in HK.

Design of PMT support structure

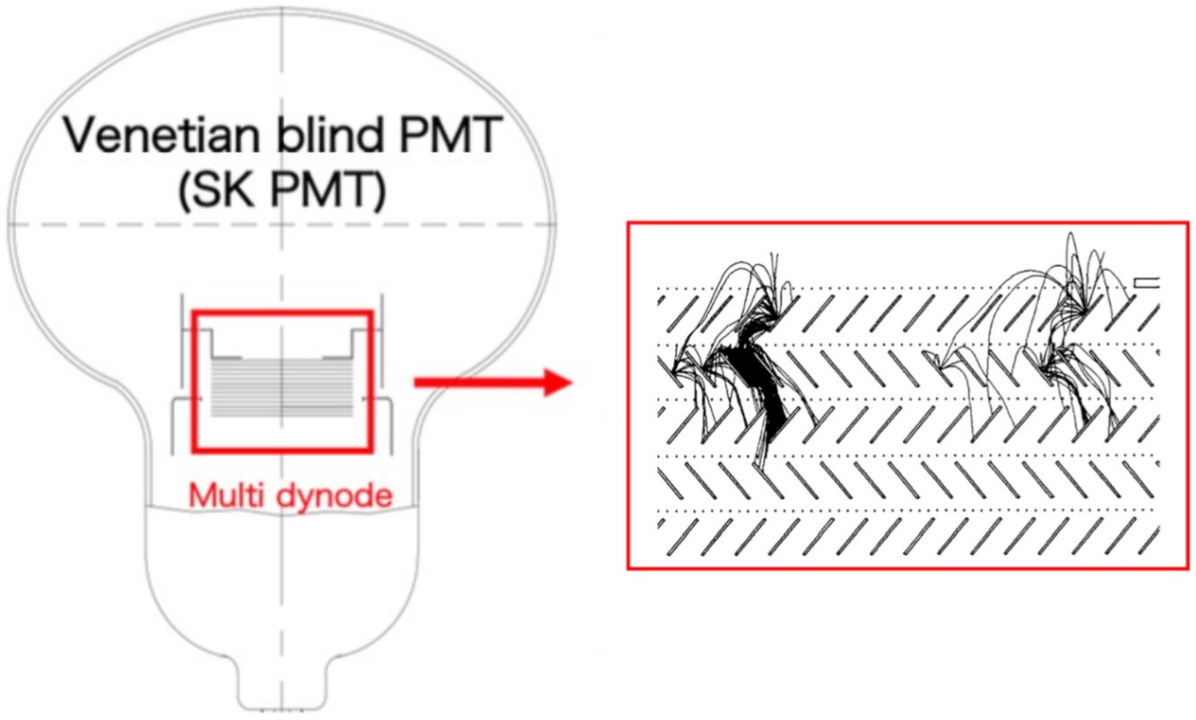
- A mockup system of the PMT support structure was built in ICRR.
- Design of PMT support structure and installation method are being studied to realize efficient and precise installation.

Summary

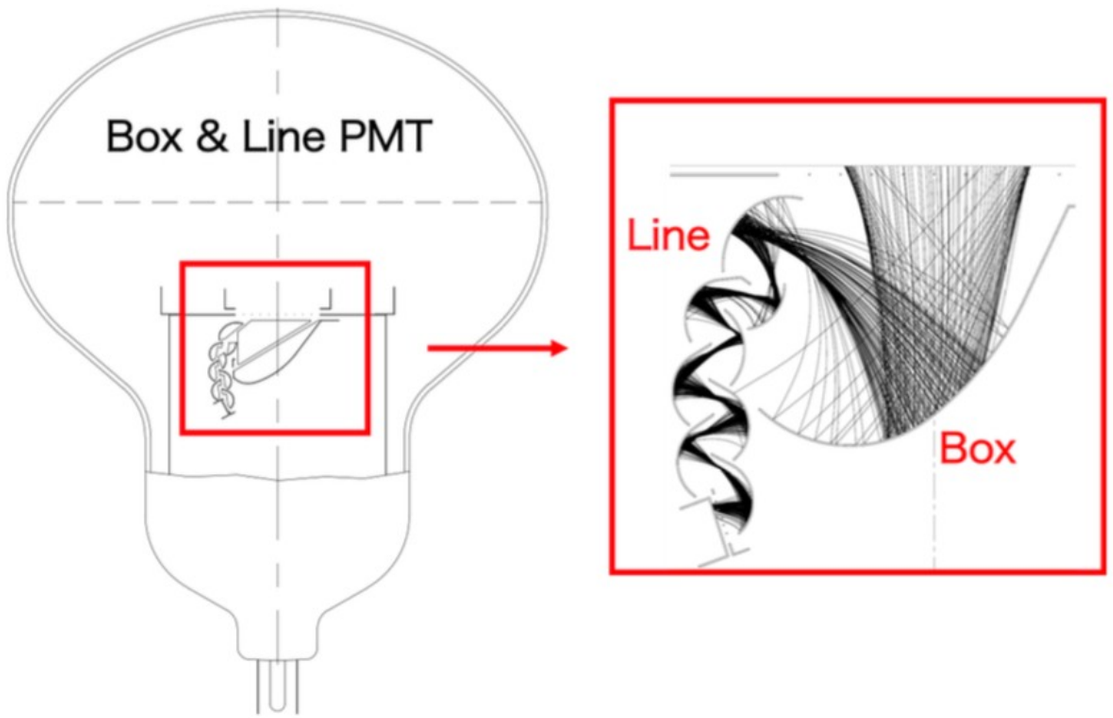
- New PMTs for HK experiment are being prepared.
- Box&Line PMT and MCP PMT were developed for HK.
- The performance of new PMTs was evaluated and proved to show better performance than SK PMTs.
  - Box&Line PMTs were installed into SK in the evaluation.
- The dark noise rate of Box&Lime PMT was reduced to **~4kHz**. Finally achieved out goal.
- The preparation of covers and installation system are also ongoing.
  - Implosion test is scheduled for covers evaluation.
  - The installation is being studied using mockup system.

Back up

Box&Line PMT



- **Venetian blind PMT**
  - Used in SK
  - QE ~ 22%
  - Multi-dynode structure



- **Box & Line PMT**
  - Developed for HK
  - QE ~ 31%
  - Box&Line dynode structure

Dark noise measurement setup