

Twenty-inch PMT development for Hyper-Kamiokande

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For Hyper-Kamiokande proto-collaboration

NNN18

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History of 20-inch PMTs for large water Cherenkov detectors

Hamamatsu R1449



**for Kamiokande
(1983 – 1996)**

Awarded IEEE milestone
(2014)

R3600

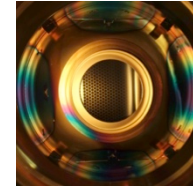


for Super-K (1996-)



Cover for Super-K (2003-)

R12860-HQE



(Box&Line dynode)

for Hyper-Kamiokande

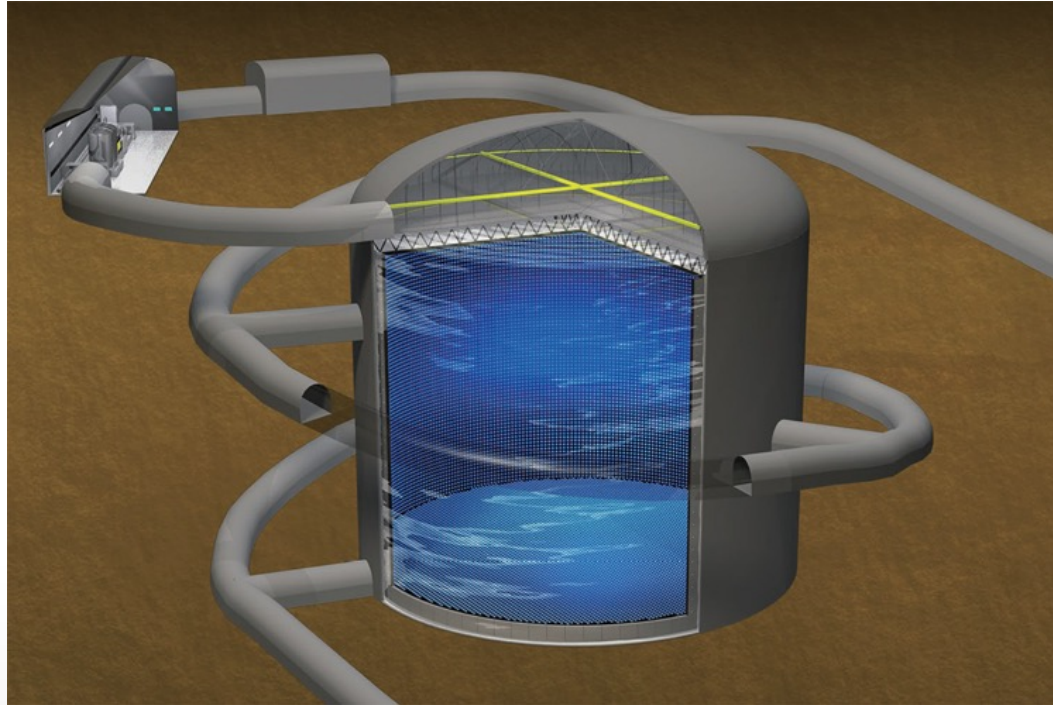


Other candidates:
(Hybrid-PMT,
MCP-PMT)

- Above 30 years continuous experiments with Water Cherenkov detectors in Kamioka.
- Many experiences, established methods.
- Photo-multiplier tubes (PMTs) are the key of large water C detectors.
- New step:
Hyper-Kamiokande.



Hyper-Kamiokande

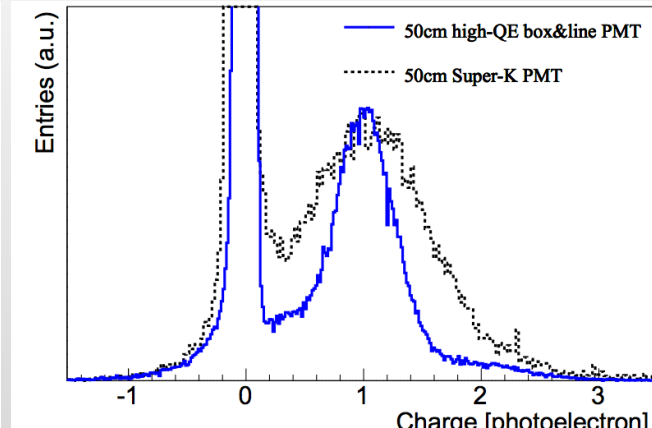
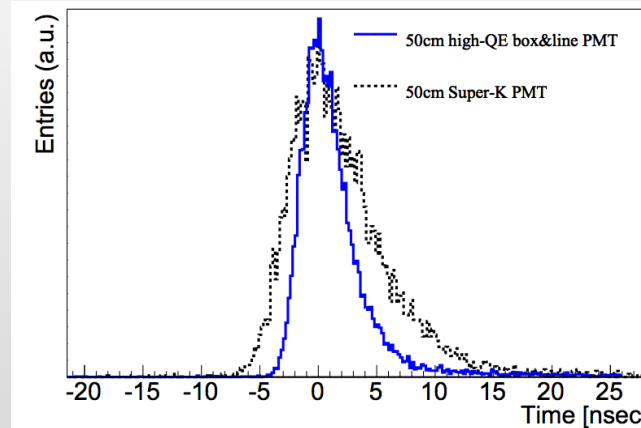
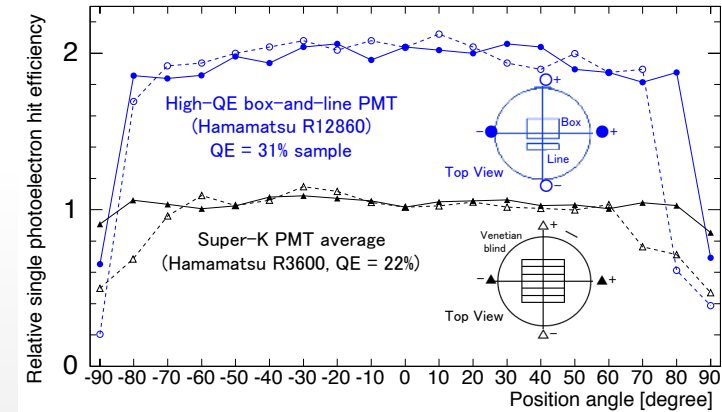


- Next generation huge water C detector
 - H60m × ϕ 74m water vol., 186kton fid.vol.
- 40% Photo-coverage with newly developed High QE PMTs.
 - About twice of QE than R3600 (Super-K).
 - Better resolutions on timing and charge

Broad Science targets:

- Comprehensive study of neutrino oscillation
 - CP violation
 - Mass hierarchy
 - Precise measurement of parameters (θ_{23} , Δm^2_{32} , ..)
 - Non-standard ν oscillation.
- Astrophysics (Supernova, solar)
- Study of Grand Unified Theories

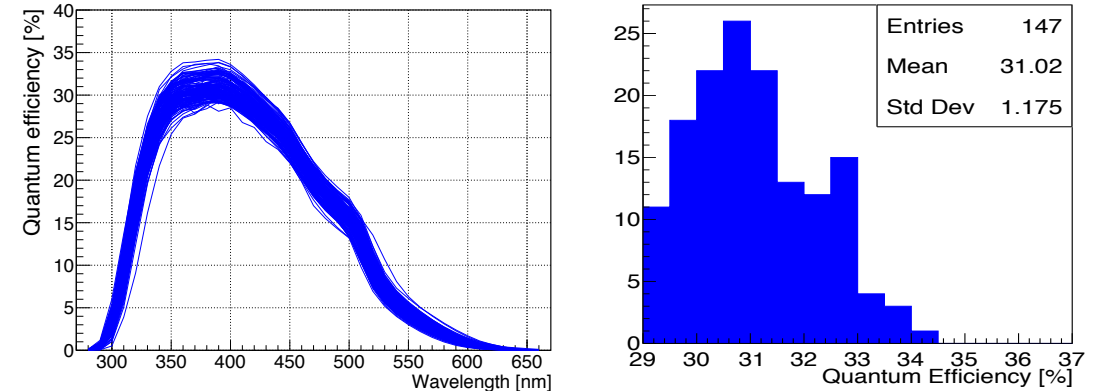
A few MeV to over 100GeV interactions.



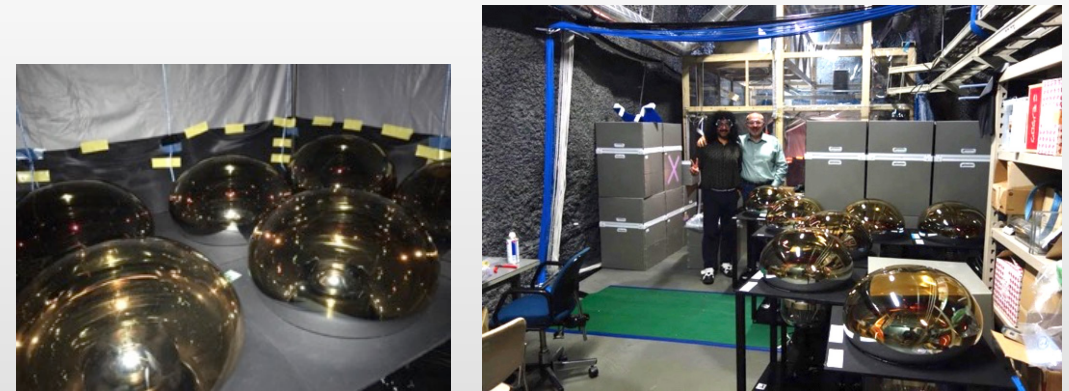
Status of development of Photo-sensor for HK

- About 150 of R12860 were manufactured for Super-K refurbishment.
 - All were screened by high pressure test up to 0.95 MPa.
 - Good responses were confirmed in Kamioka laboratory (next page).
 - No rejected PMTs over 30kHz in short stabilization (half - a few days)
- We installed them in Super-K this summer, and will evaluate performance inclusively in water Cherenkov detector.
- R&D for reducing dark rate with optimizing design / production.

Quantum Eff. at Hamamatsu.

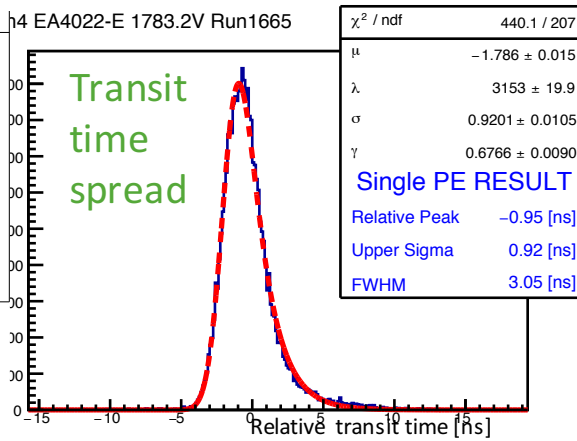
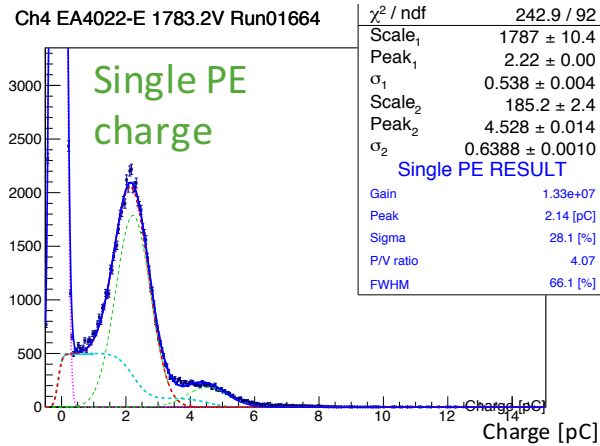
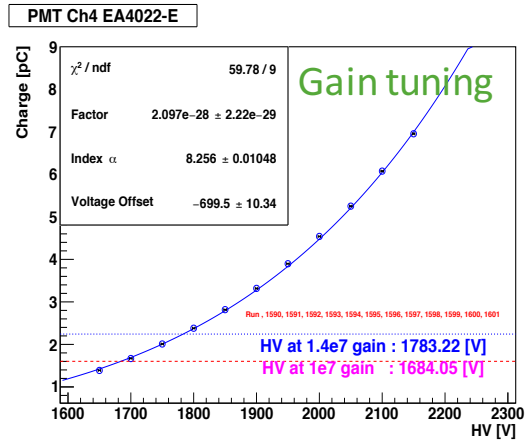


Kamioka underground laboratory, Mar. to June, 2018,



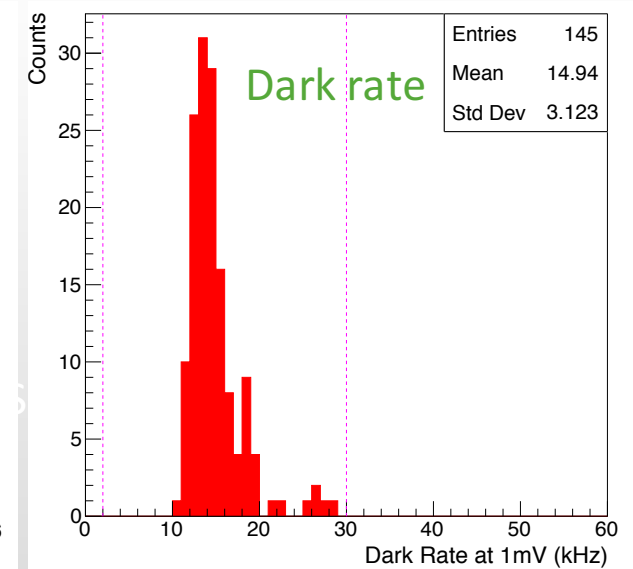
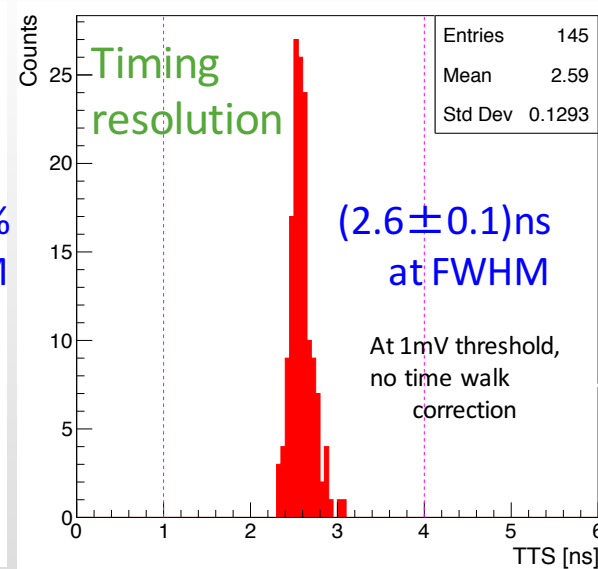
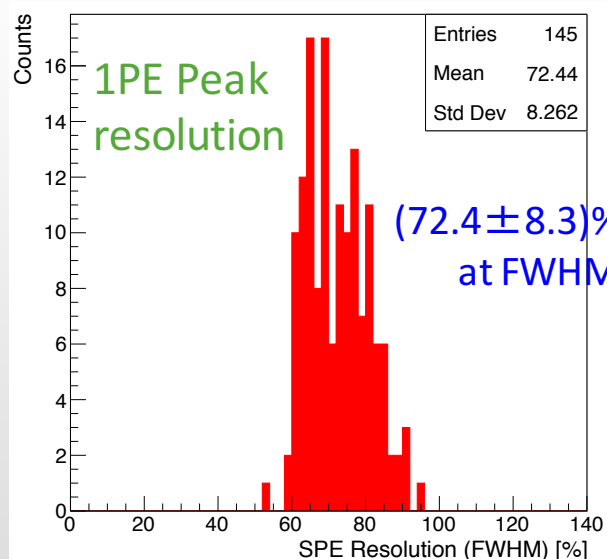
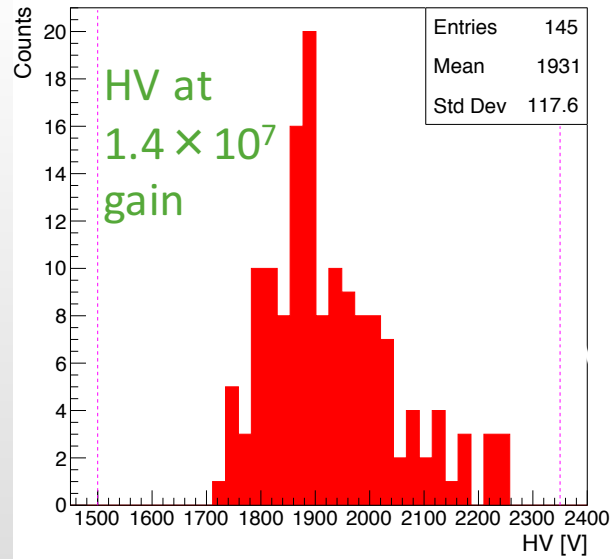
Quality measurement of ~150 PMTs (R12860-HQE)

Example of an evaluation



- Evaluation of 145 PMTs are done in Kamioka underground.
- Performance well controlled.
 - Around 10% variation.
 - HV at target gain in reasonable range.

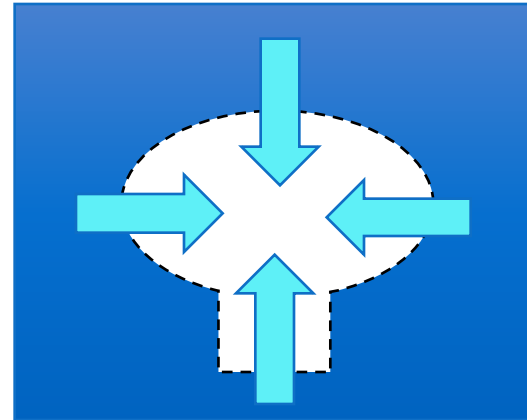
Stat. of the PMTs



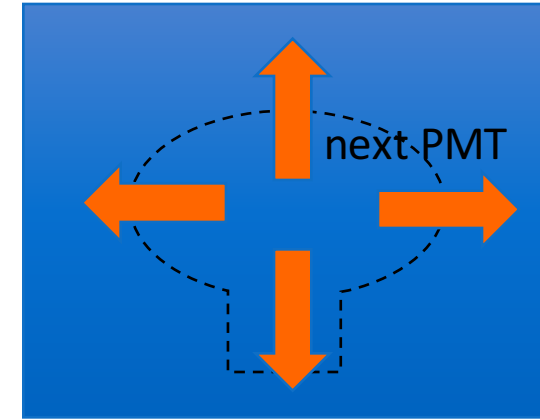
Ready for mass production with a good quality control.

Why PMT cover is needed for huge liquid detector

- A crash of a big PMT in deep liquid (water) generates a rush of inflow and their collisions. It generates shock wave.
- Shock wave crashes next PMTs, and new shock wave is formed. → Chain implosions.



Rush of waters to vacuum & collision



shockwaves

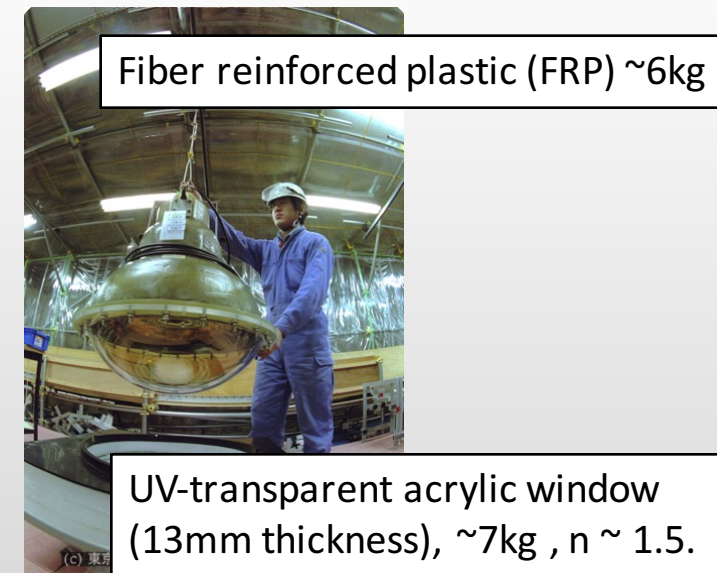
Prevention of the chain implosion is necessary for big liquid detector.

- Relax water rush to vacuum & reduce the shockwave.
- Protect from shockwaves.

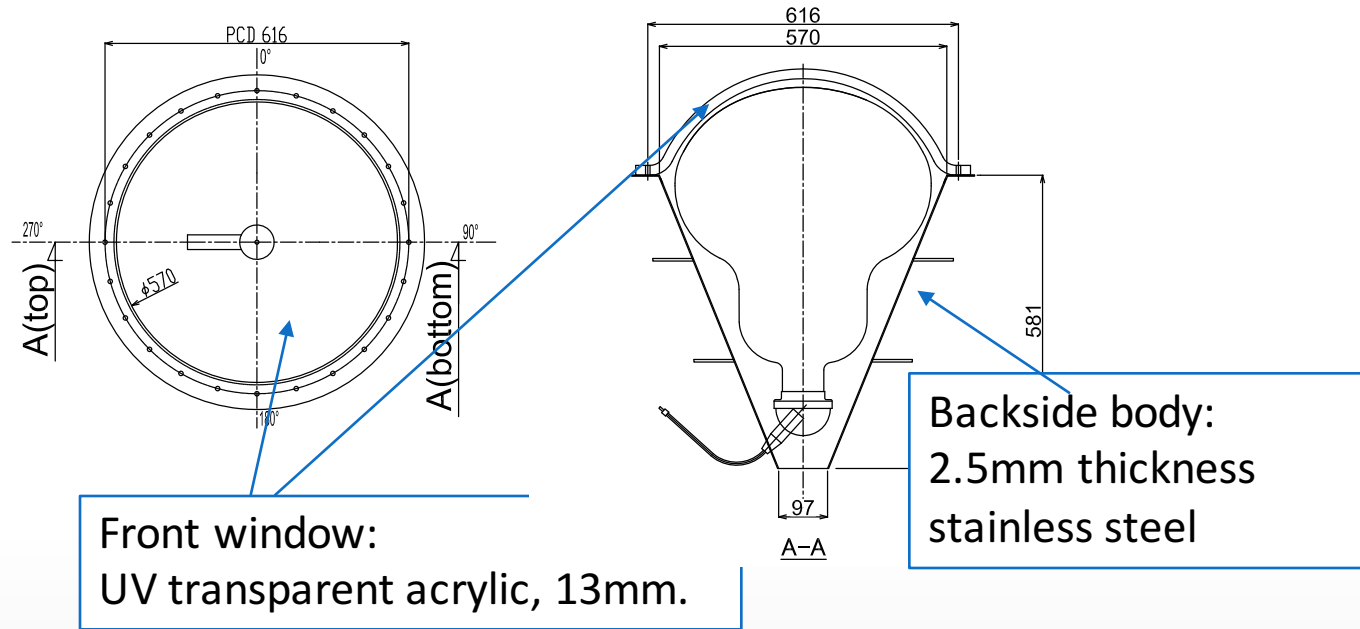
→ **PMT cover to prevent chain implosion.**

History

- First cover was development for Super-Kamiokande in 2003.
- Relevant for 40m depth.



PMT cover development for Hyper-Kamiokande



Should be secured at deeper depth (60m).

Other important issues:

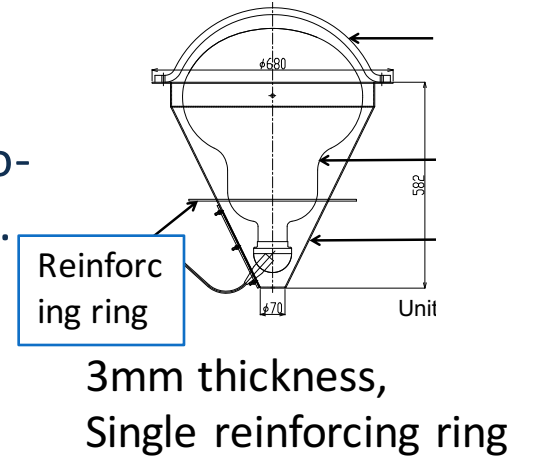
- Effect on water quality (material emanation)
- Radio activity, contamination, chemical luminescence, etc.
- Connection method is one important issue.

PMT cover also determines the performance of photo-detector. (aperture, dark hit rate). Should be well considered.

Hydrostatic test and actual test of prevention of chain-implosion was carried out.

By 2016

Establish a proto-
type for Hyper-K.



2017 to 2018

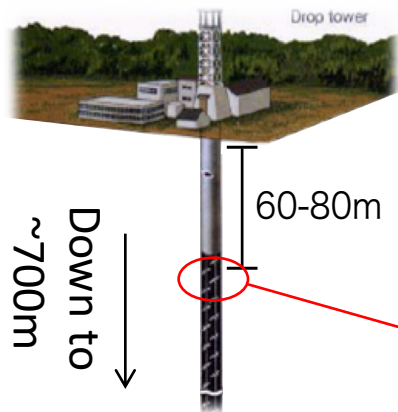
Improvement of the design

- Lighter weight
- Reducing production cost

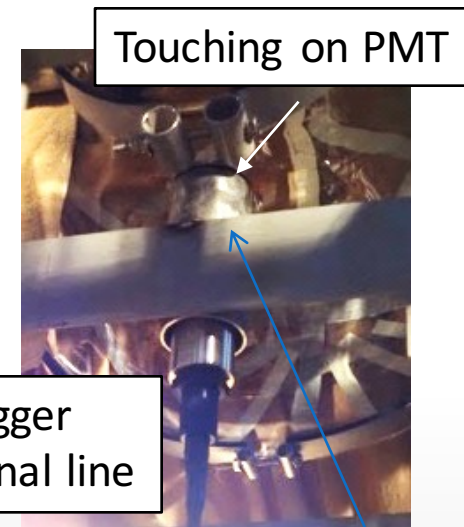
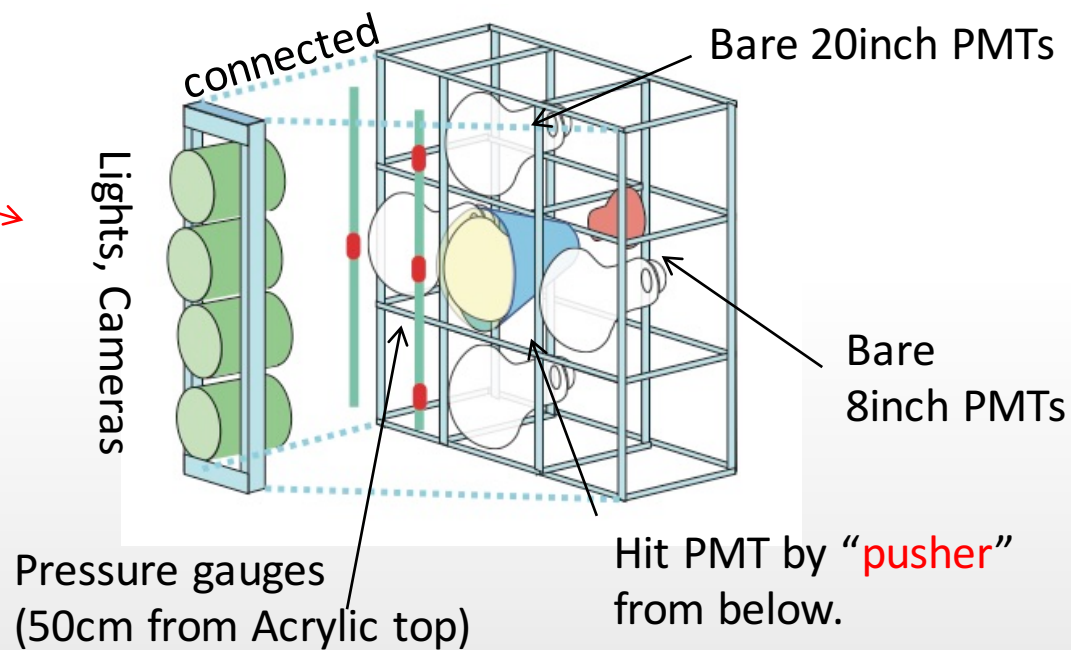
Alternative designs

- Different material (Resin)
- Different shape and/or production method

Chain implosion test in deep water (Mar. 2016 & Mar.2018)



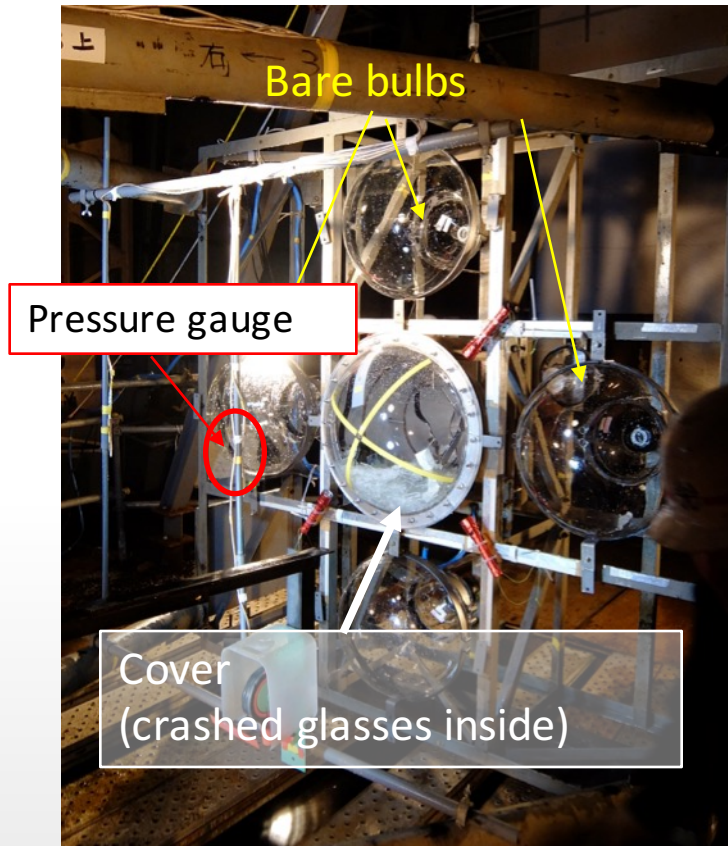
- Old Micro-Gravity laboratory in Kami-Sunagawa town, Hokkaido, Japan.
- Long vertical shaft filled with natural spring water.



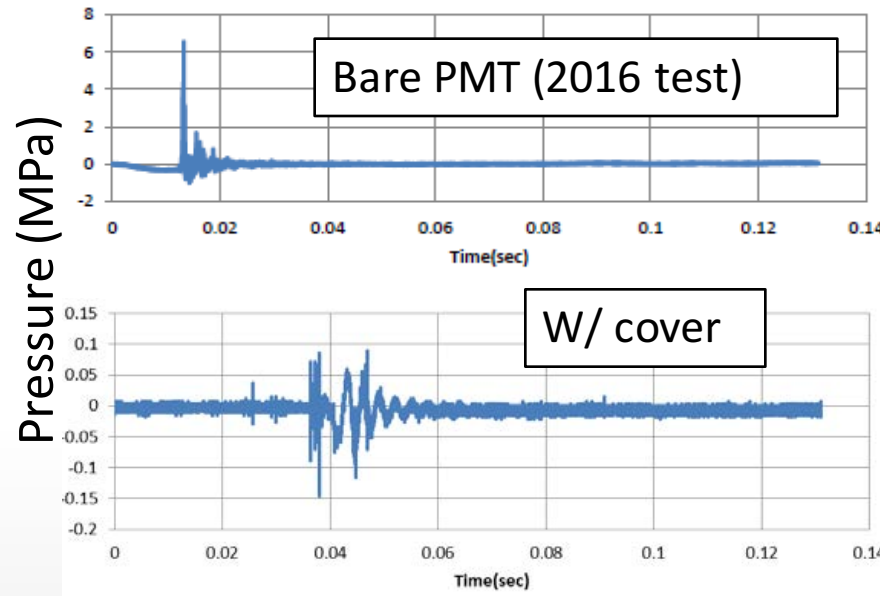
Piston driven by chemical reaction

- Place a PMT bulb with cover surrounding a bare bulbs.
- Place it on deep water (80m is a target for HK), and crash bulbs with a 'Pusher' remotely.
- Test the effect to neighboring bulbs.
- Also record pressures, strains, and high-speed visual data.

Result of chain-implosion test (Mar. 2018)

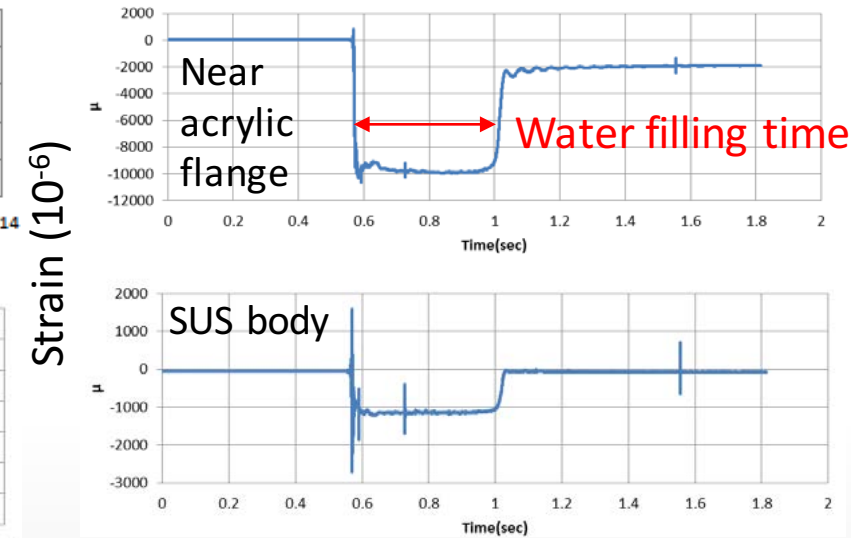


Pressure gauge at 50cm from cover front

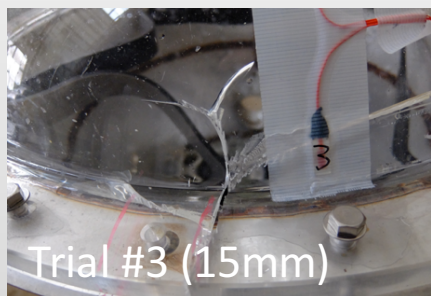


For bare PMT, about 6M Pa shockwave.
Cover reduces shock wave down to $O(1/100)$

Strain gauge



Common sharp peaks are electric noise of recorder.

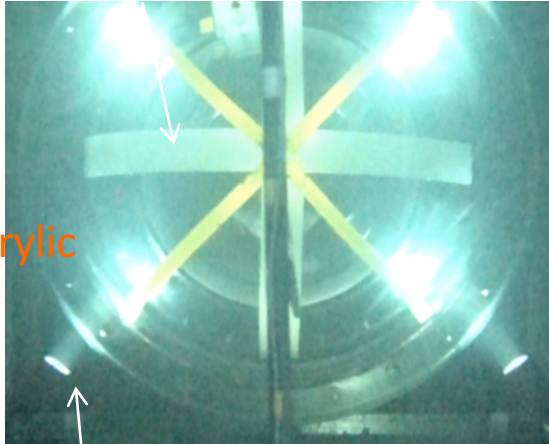


- Succeeded to prevent chain implosion three times consecutively at 80m depth.
- We decide it is OK for Hyper-K.
- Shockwave reduced down to $O(1/100)$.
- We found cracks on acrylic flange around connection part to main frame. Improvement of fixing method is on-going.

High speed camera (80m depth)

Tapes on glass (white)

Tapes on Acrylic
(Yellow)



Light



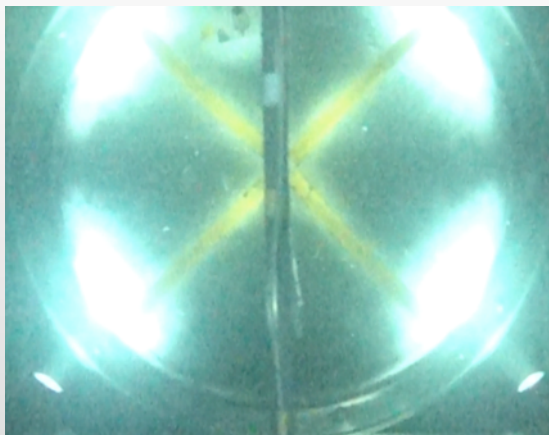
Pusher



+ 3frame / 960fps
= ~3ms



+ ~6ms



+ ~0.8sec

- Commercially available digital camera (Sony RX100) + handmade trigger system. Key was lighting.
- We clearly see the steps of the implosion processes.
- Implosion pattern, speed depends on the cover. Water inflow to PMT is a key of the phenomena.
- Will give us useful information for next R&D.

Alternative cover design (1) :Resin-made cover



PPS + 30% CF

Physics spec.

- Density **1.46g / cm³** (SUS 304 **7.9g/cm³**)
- water absorption 0.02% @ T=23 deg.

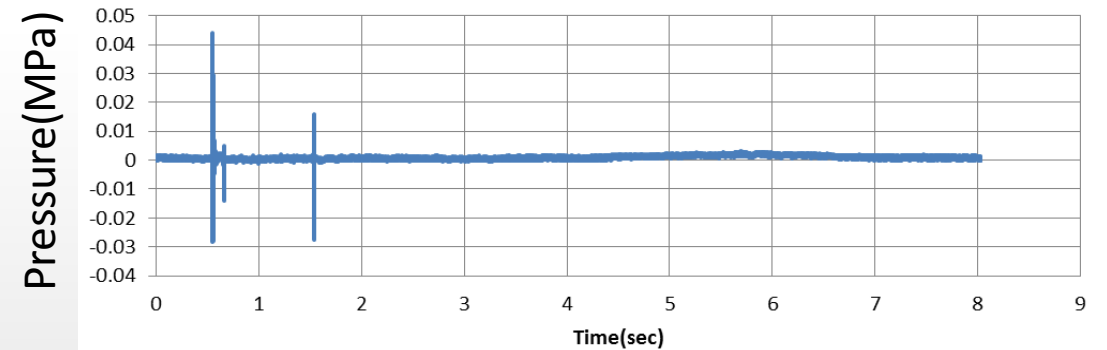
Mechanical spec.

- Tensile strength: 236MPa
- Bending strength: 342MPa
- Compression strength: 294 MPa

U-chain [Bq/cover]	<0.27
UpperU [Bq/cover]	<3.42
Th-chain [Bq/cover]	<0.22
60Co [Bq/cover]	<0.06
40K [Bq/cover]	<2.34

No visible radioactivity

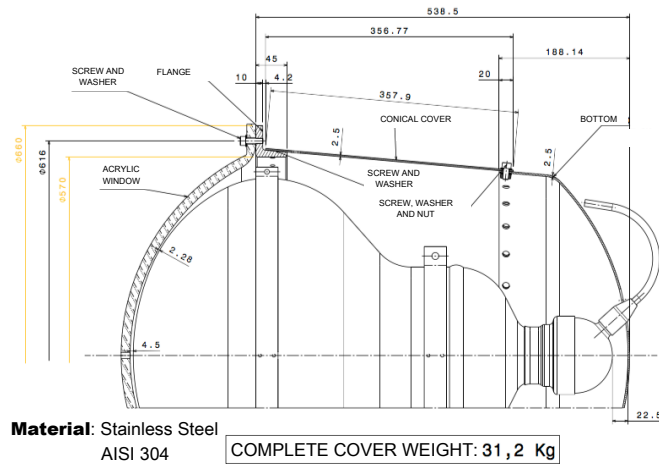
Gauge at 50cm from cover front



- Monolithic resin-made cover + FRP window.
- Poly-phenylene Sulfid (PPS) + 30% carbon fiber (CF).
 - Thickness ~5mm, about 6kg.
 - RI contamination, emanation to pure water is important issue.
- Injection molding is employed for PPS cover.

- Passed single trial at 40m water depth, but failed at 60m.
- Improvement of design / material selection are on-going

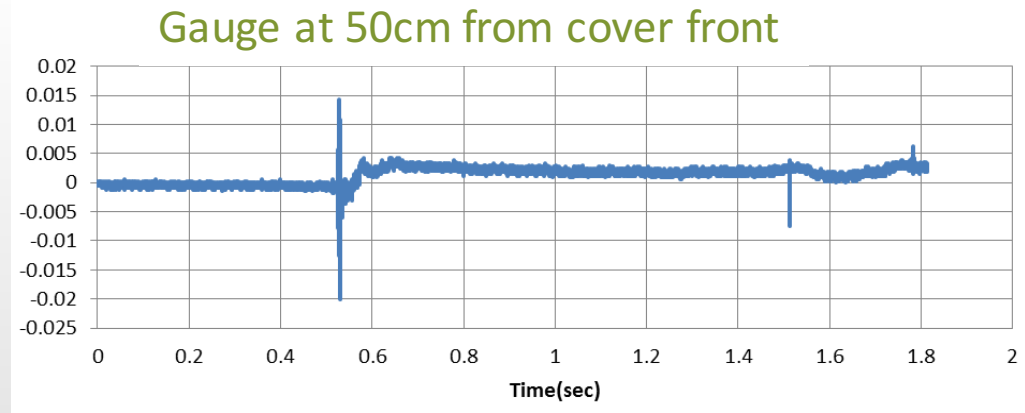
Alternative cover design (2) : Tube-like cover



- 2.5mm thickness stainless steel tube + 3mm thickness endcap by stamping molding.
- 10mm thick flange.
- 15mm acrylic window.

- Spanish colleague's contribution.
- Simple structure. Cheaper production cost is expected.
- Able to disassemble. Easy to transport. Cheap shipping cost.
- Rather heavy, about 31kg.
- One trial at 60m, and succeeded.

Pressure (MPa)



- About 1/5 of shockwave than other cover.
- Slow water filling, due to small aperture.

Installation of Hyper-K PMTs / covers in Super-K

- About 140 of R12860 are installed in Super-K instead of R3600.
- We also installed Hyper-K covers: Eight of stainless steel cover, two of PPS resin-made cover.
- It will give inclusive evaluation of Hyper-K photodetector system.

View of Super-K top from back side



Fixing structure to the tank is modified for Super-K.

Summary

- New PMT (R12860), 20-inch High QE PMT, was developed.
 - Full photon detection method is established.
 - Good prospect for mass production.
- PMT cover has been developed for Hyper-K.
 - Works to prevent chain implosion at 80m depth.
 - Improvement / alternative design is on-going.
 - Connection between cover-PMT or cover-HK structure is important issue. It is under study.
 - Plan to decide the design the cover in next couple of years.
- HK PMT + covers were installed in Super-Kamiokande.
 - Will give us a inclusive evaluation of the photon detection system.