

Development of 50 cm Photo-Detectors for Hyper-Kamiokande



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On behalf of the Hyper-Kamiokande Proto-Collaboration



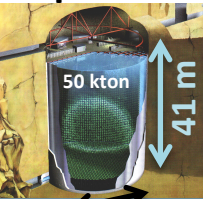
RCCN, The University of Tokyo

ICHEP 2018 @ Seoul, Korea

6/July/2018

50 cm Photo-Detectors for Hyper-Kamiokande

Super-Kamiokande (Super-K)

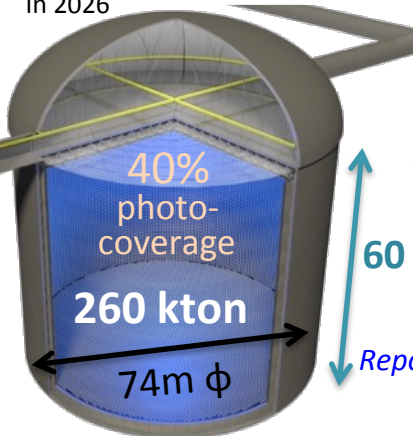


Large Water Cherenkov detector in Kamioka, Japan

41 m
39.3 m ϕ
 $\times 11,129$
50 cm ϕ Photomultiplier tubes (PMTs)

Hyper-Kamiokande (Hyper-K)

Plan to launch in 2026



60 m

$\times 40,000$

- ν oscillations
 - ▶ Leptonic CP violation
 - ▶ ν mass hierarchy, ...
- Nucleon decay discovery
- ν astrophysics
 - ▶ Supernova burst ν , ...

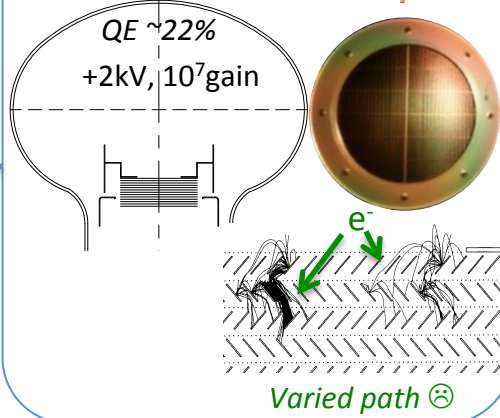
Report today

New photo-detector covers were tested in deep water.

Super-K PMT

Hamamatsu R3600

Venetian blind dynode



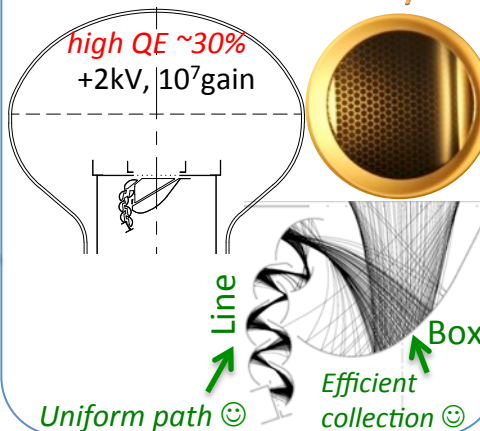
→ Performance was improved in two newly developed photodetectors for Hyper-K.

- $\times 2$ high detection efficiency
- $\times 1/2$ time & charge resolutions
- $\times 2$ high pressure bearing for 60 m height

Box&Line PMT

Hamamatsu R12860

Box & Line dynode



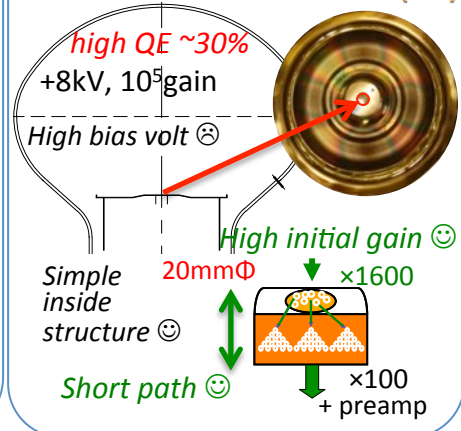
Ready for mass production.

Over 100 PMTs were prepared for operation.

HPD (Hybrid PhotoDetector)

Hamamatsu R12850

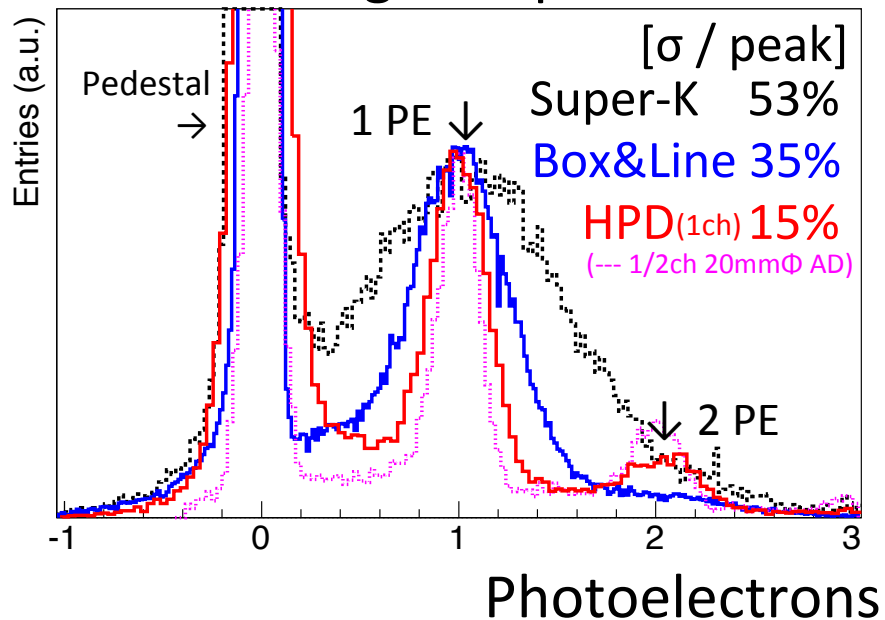
Avalanche diode (AD)



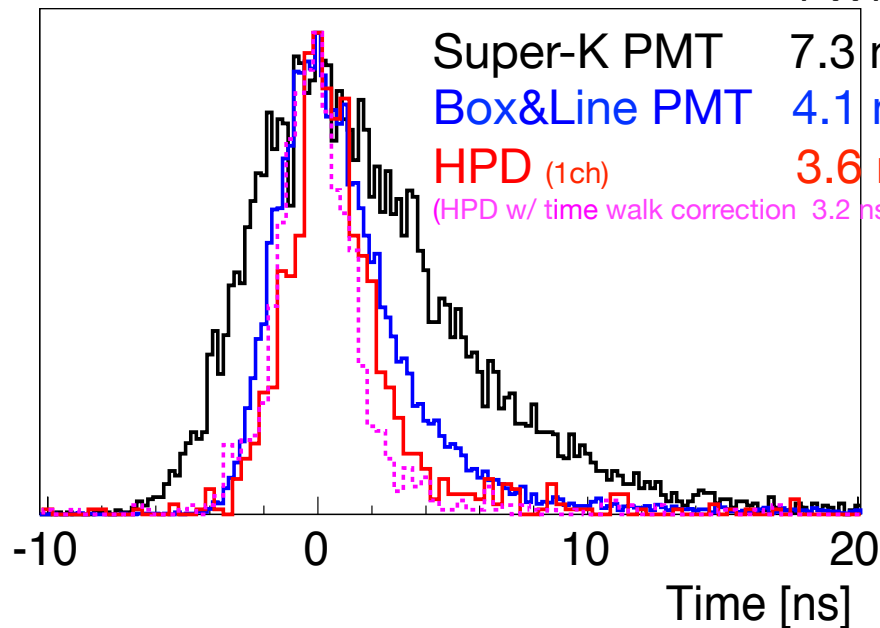
HPD was installed in a small water tank with improved preamplifier.

High Resolutions

Single PE peak

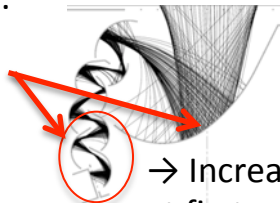


Single PE transit time spread_{FWHM}

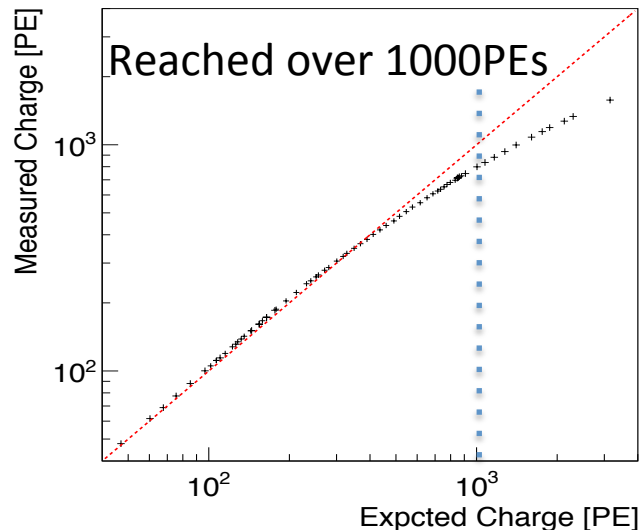


Improvement on the Box&Line PMT

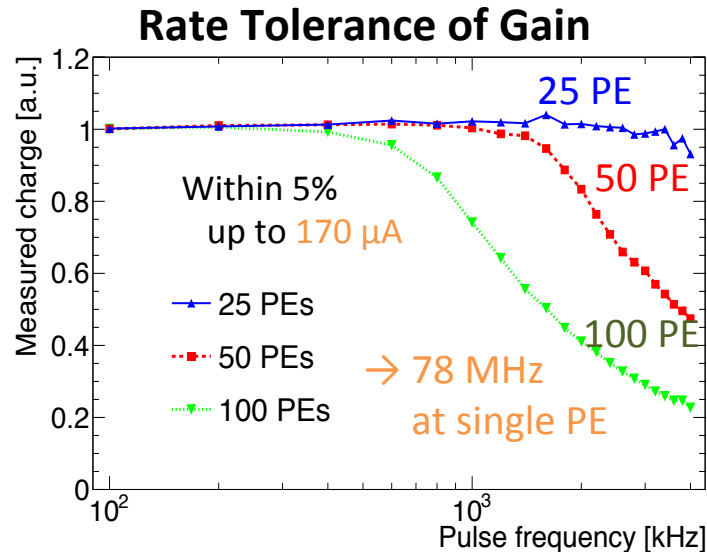
Dynamic range was improved to detect wide energy range of MeV-GeV v.
Optimized voltage dividing ratios without losing performance.
5.2V \rightarrow 7.5V max (~ 6 mV/PE) in a sample.



\rightarrow Increased voltage at first and latter three dynodes.



\rightarrow Confirmed sufficient high rate tolerance
for supernova burst detection (10MHz at max in low PE)

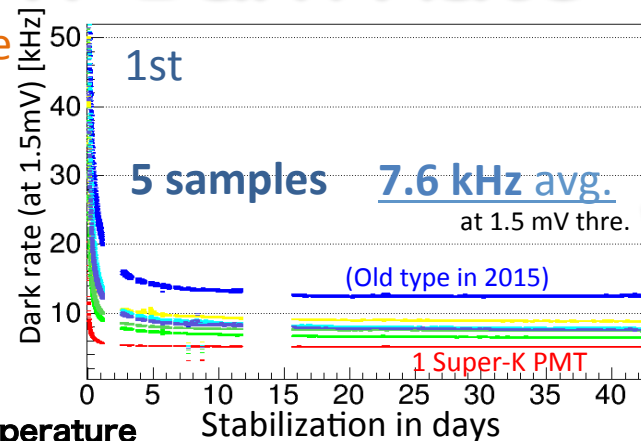
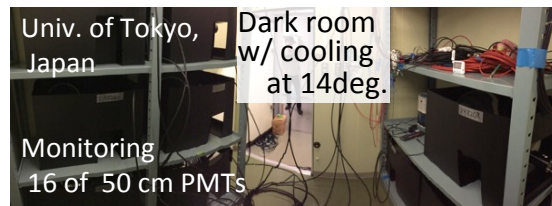


Study on the Box&Line PMT Dark Rate

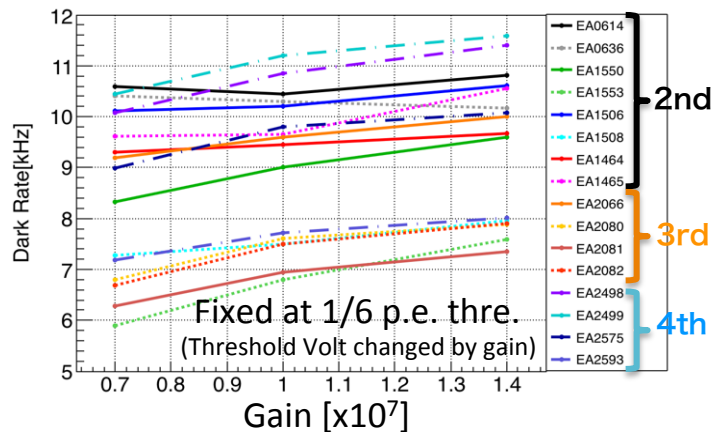
Optimizing photocathode production to minimize the dark rate

○ 20 kHz → 10 kHz → 8 kHz (1st) → (2nd) → (3rd) → (4th) → ...
 2014 2015 2016.Aug 2017.Apr Jun Jul

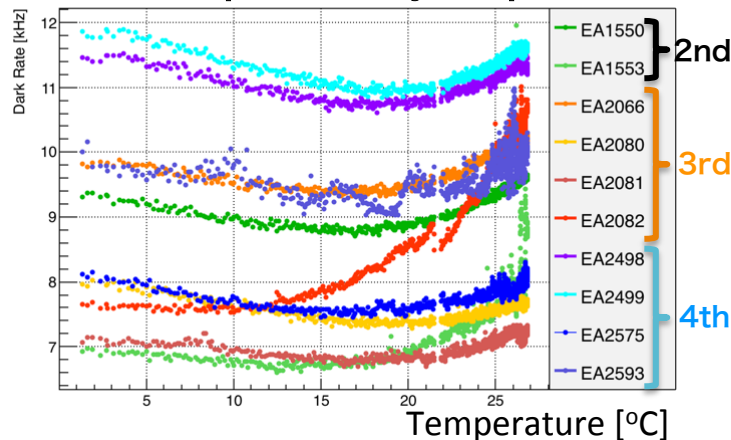
Measured a stabilized level of dark rate after a few months



Dark rate dependence by gain (HV)



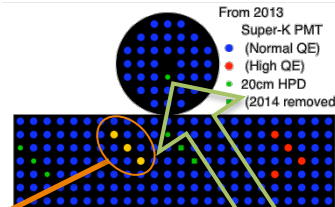
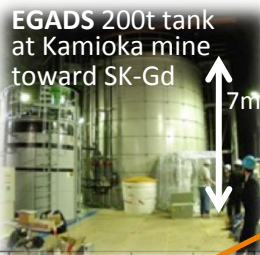
Dark rate dependence by Temperature



Studies for dark rate reduction are ongoing with reconsidering material / structure inside in a year.

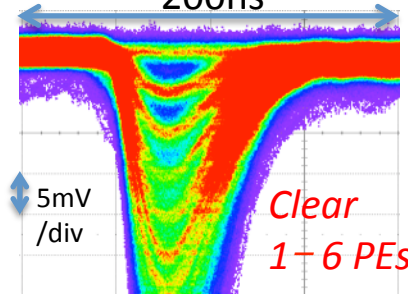
Proof Test in a Water Cherenkov Detector

- Testing initial type of 3 **Box&Line PMTs**
 - in a 200-ton water Cherenkov detector (EGADS) since 2014.
- Working for ~3 years stably!



50 cm ϕ HPD

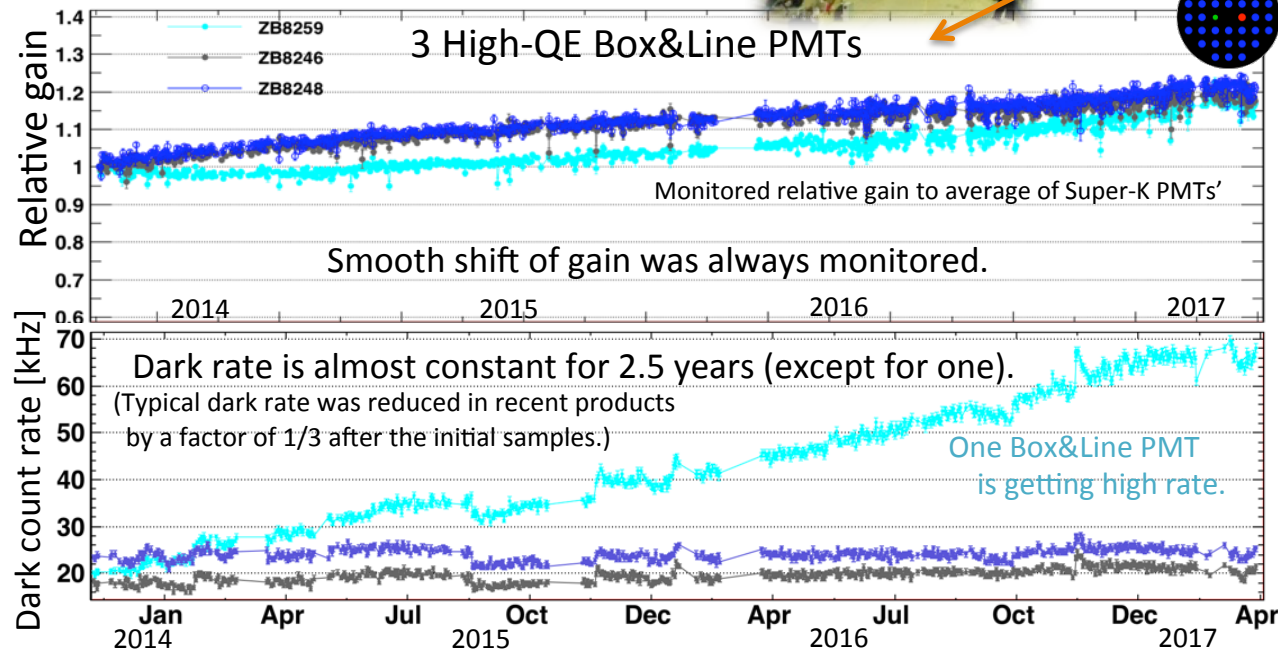
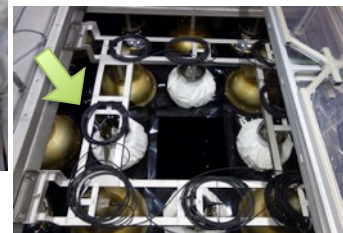
200ns



Developed 1 waterproof HPD with preamplifier improved for narrow pulse width.



Installed the HPD in late 2017.



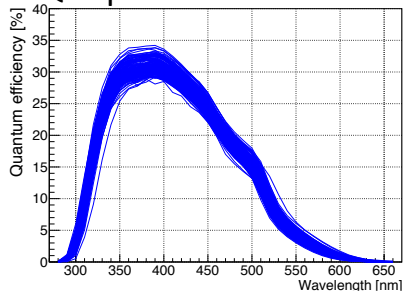
2018/Jul/6

Development of 50 cm Photo-Detectors for Hyper-Kamiokande

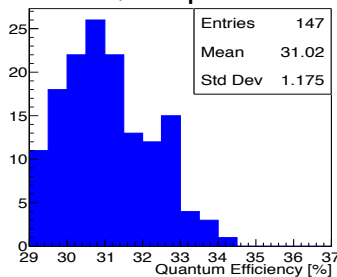
Quality of Box&Line PMT Production

~150 Box&Line PMTs were manufactured.

QE Spectra of ~150 PMTs

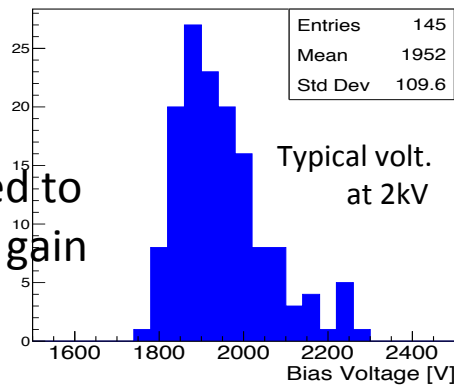


QE at peak



HV at 1.4×10^7 Gain

HV
calibrated to
 1.4×10^7 gain

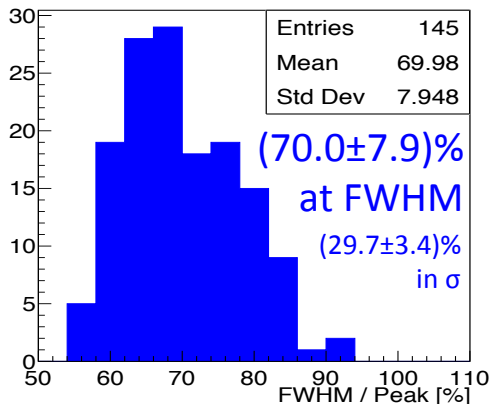


Within reasonable operation range

- All PMTs were screened at high pressure water up to 0.95 MPa.
 - No damage found in the bulb.
- Calibrated all PMTs at Kamioka, JP.
 - Gain, resolutions, dark count rate, etc.
 - No rejected PMTs by performance in our tentative criteria for Hyper-K.

Resolutions at single photoelectron peak

FWHM at 1.4×10^7 Gain

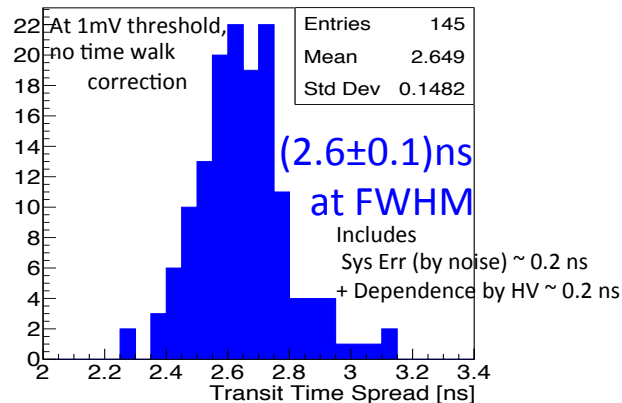


Around 10% variation for single PE detection

Mar-Jun 2018, in dark room



TTS at 1.4×10^7 Gain

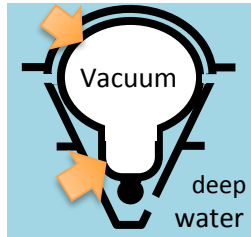


Ready for mass production with a good quality control.

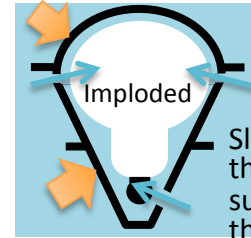
Photo-detector Covers

- Accidental implosion of bulb in water might cause a chain implosion by a shock pulse.

- A shockwave prevention cover made of FRP was developed for Super-K for 40m depth.



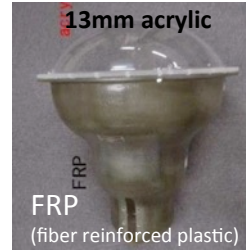
Usual case
Bulb is
pressurized.



Implosion
Cover is
pressurized.

Slow water flow
through cover holes
suppresses
the shockwave.

Super-K cover
for 40 m water depth



- New covers were developed for a deep Hyper-K tank up to 60 m with clean materials.

- A cover made of stainless steel was developed for Hyper-K and established with tests in 2016.
 - Further improvement with light weight or low cost for several designs

In 2016

Initial prototype
for 60 m water depth



Stainless steel (3 mm)
Weight
w/o acrylic 22kg

1. Improved cover



17kg

Cover
pressurized
test in water
→ 1 MPa

2. Resin cover



6.4kg

PPS
(Poly Phenylene Sulfide)
with carbon fiber

0.5-0.57 MPa

Light weight,
fast and easy
mass production

3. Stainless steel tube cover



30kg

0.7 MPa

Cheap and
simple,
Developed
in Spain

New 3 covers were also tested with bulb implosion inside in 2018.

Development of 50 cm Photo-Detectors for Hyper-Kamiokande

Validation of the Covers

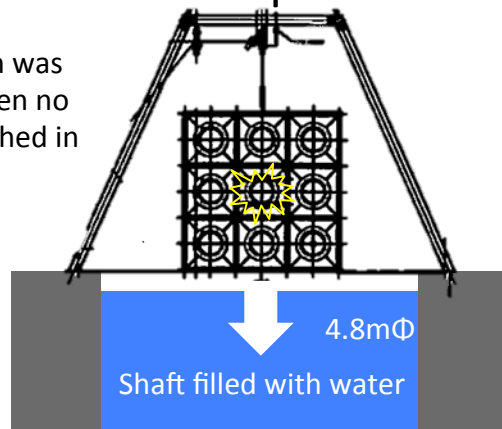
In Hokkaido, JP



The covers were tested in a deep shaft at 40-80m depth with the bulb implosion.

- Procedure
1. PMT is imploded in the cover by a hitting tool with surrounding PMTs without cover.
 2. Confirm the cover and surrounding PMTs have no damage with monitoring the shock.

Chain implosion was reproduced when no cover was attached in 2016.

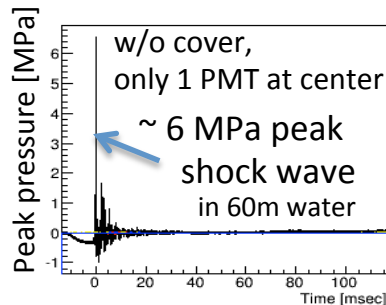
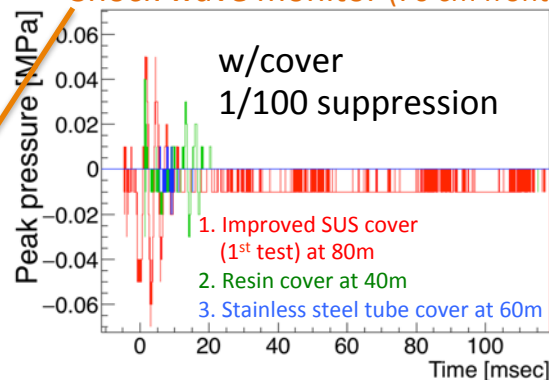


The second test was performed in Mar 2018.

1. Improved cover

→ Success at 80 m three times

Shock wave monitor (70 cm front)



2. Resin cover

Success at 40 m (1 test only), but failed at 60 m

Next: To be reinforced with optimizing design and injection material.

3. Stainless steel tube cover

Success at 60 m (1 test only)

Next: Reduce weight, reach easy mass production /assembly design

New stainless steel cover was established!

22kg → 17kg, 15mm → 13mm acrylic thickness



Hyper-K Photo-detector system is ready.

2018/Jul/6

Development of 50 cm Photo-Detectors for Hyper-Kamiokande

9

Installation of ~140 Box&Line PMTs in Super-Kamiokande



Many Box&Line PMTs will be practically operated in Super-K soon.

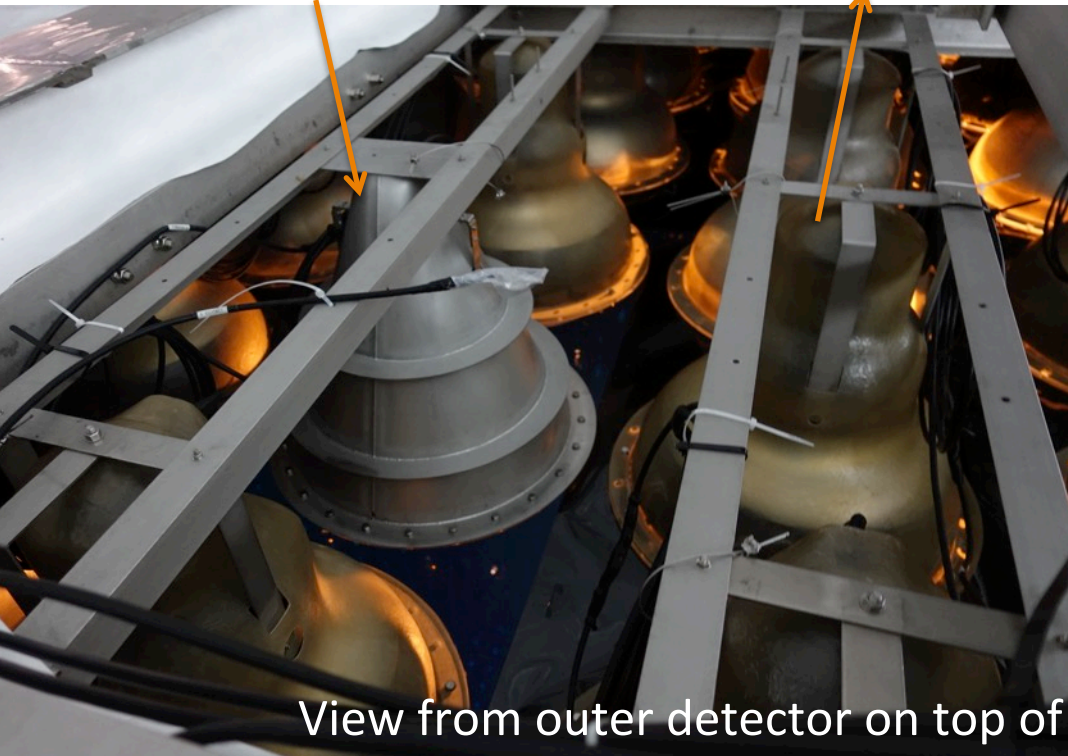
Hyper-K Covers in Super-K

10 Hyper-K covers, made of clean materials with low backgrounds, are installed in SK top/bottom.

Stainless Steel Cover

FRP cover in Super-K increases dark rate a little..

PPS Resin Cover



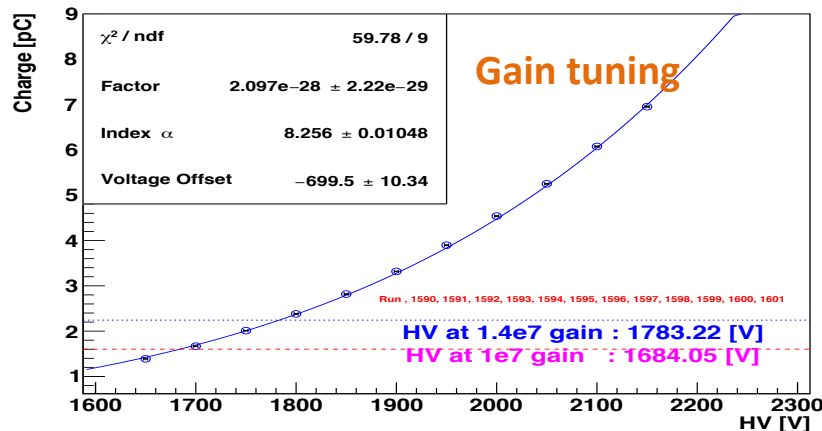
View from outer detector on top of the Super-K tank

Conclusion

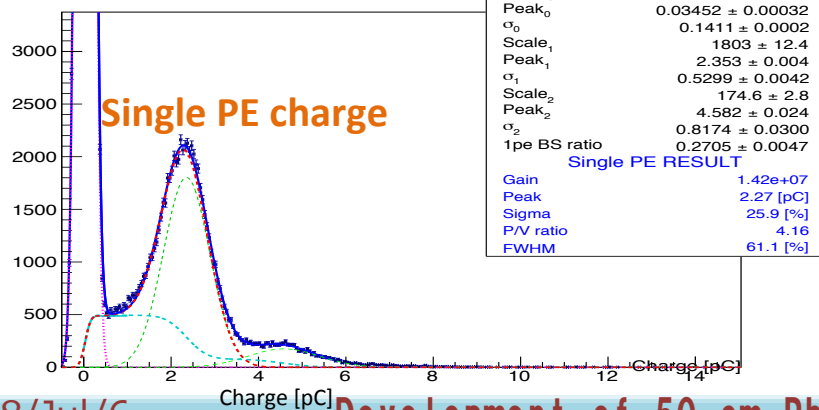
- Box&Line PMT design is ready for production.
 - We confirmed sufficient quality in the ~150 PMTs' production.
 - Installed in Super-K, some of them with the improved covers for Hyper-K.
- HPD brings the best resolutions.
 - Operation in the 200-ton water tank started.
- Aiming for start of construction in JFY2019 and operation in JFY2026

Example of Fitting on Single PE Distributions

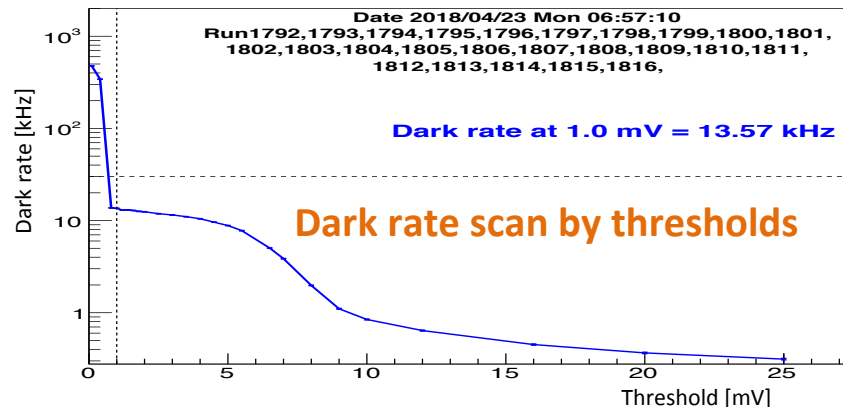
PMT Ch4 EA4022-E



Ch3 EA4022-E 1783.2V Run01788



Ch3 EA4022-E 1783.2V



Ch3 EA4022-E 1783.2V Run1789

