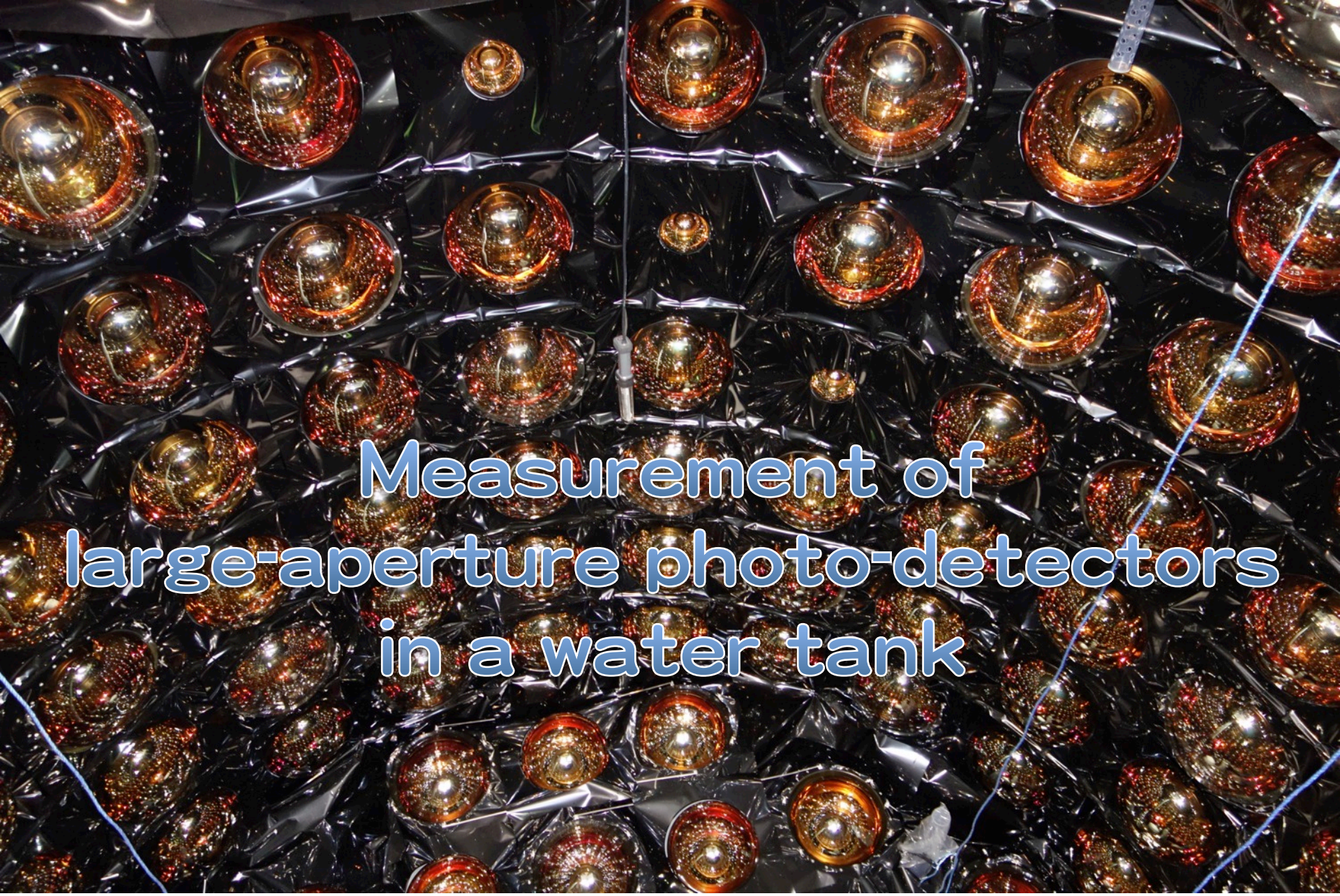


Measurement of large-aperture photo-detectors in a water tank

Y.Nishimura
RCCN, University of Tokyo

4th Hyper-Kamiokande open meeting
28/Jan/2014

Contents

- Installation report
  - 8-inch HPDs* and 20-inch high-QE PMTs were installed in a 200-ton water tank in summer 2013.

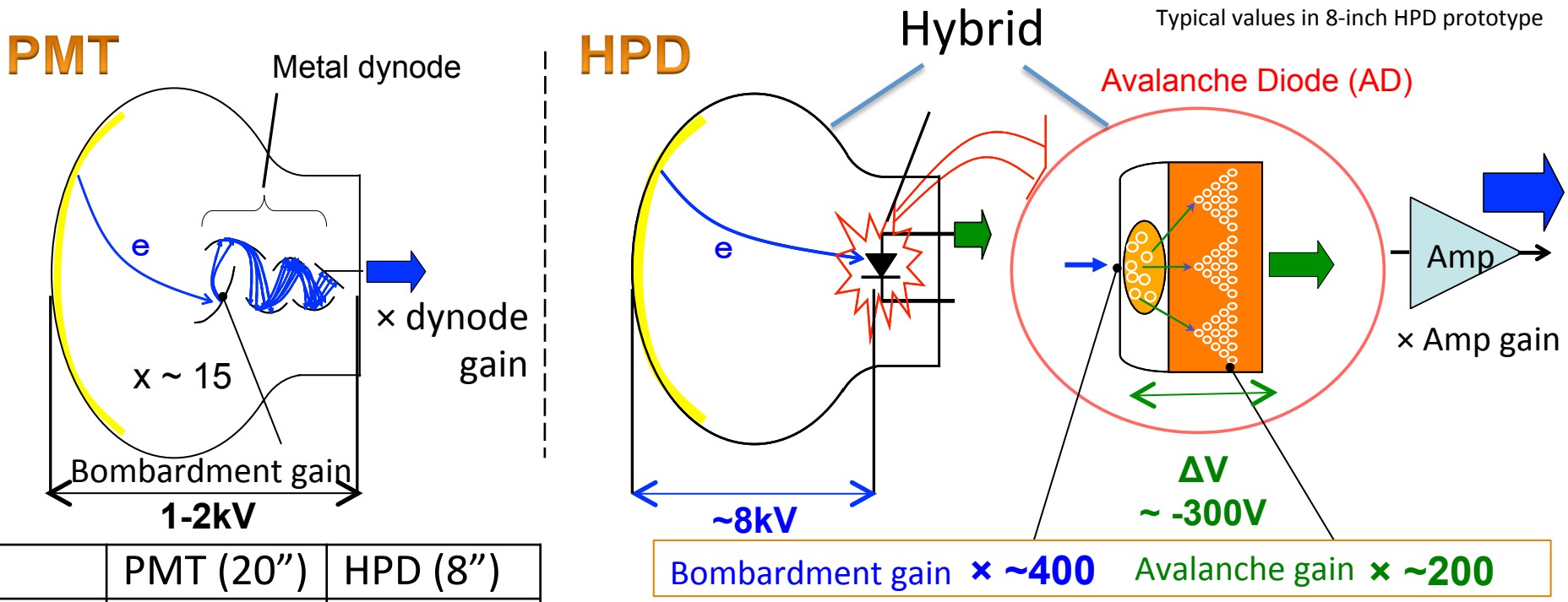
*HPD = Hybrid PhotoDetector

- Measurement status
  - Calibration and monitor are going on.
  - Long run will start soon.

- R&D of new 20-inch photo-detectors
  - High-QE box and line PMT
  - High-QE HPD

} Now being developed in Hamamatsu photonics
Tested soon in Kamioka

Hybrid PhotoDetector (HPD)



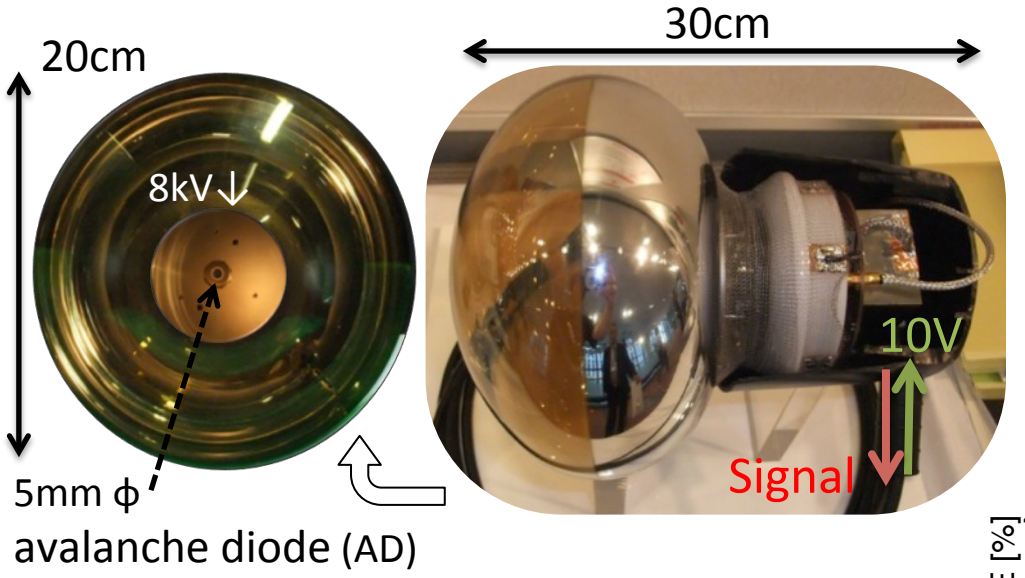
	PMT (20”)	HPD (8”)
HV	1-2kV	~8kV
Gain	~10^7	~10^4 - 10^5
C.E.	~80%	~97%

Same photo cathode (Q.E.)

High voltage around 8kV is required
- to collect electrons in the small region of AD (5-20mm)
- to increase gain at electron-bombardment

- High performance and low cost
- However, factors to consider for viability in Hyper-K are:
  - Dark noise from AD + Amp., HV around 8kV, low gain, thermal dependence of AD gain, No prior experience using

Two options for 1st proof test



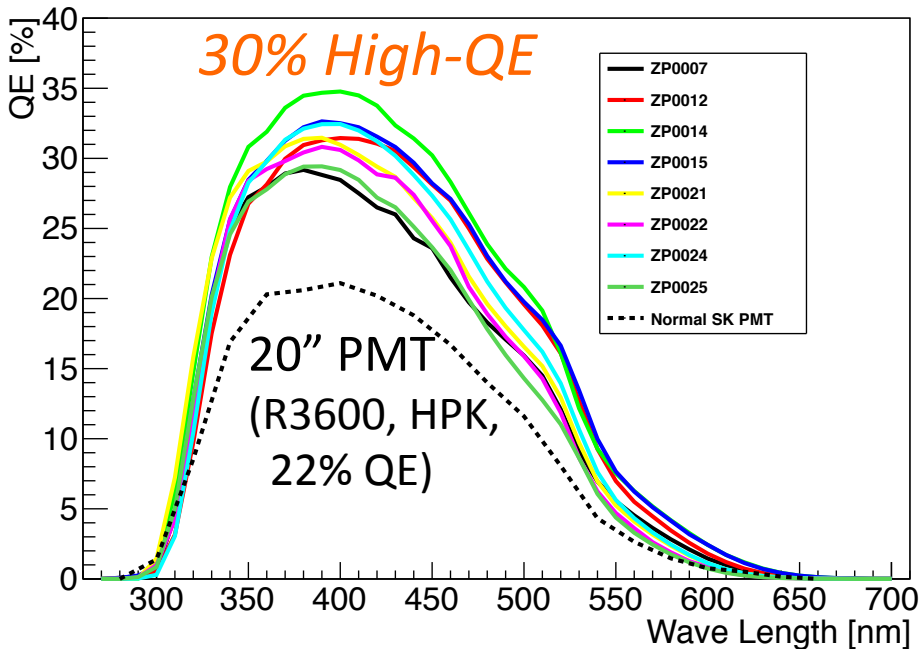
8-inch HPD

- HV module and preamplifier were built-in.
- Precalibrate 10 HPDs, install **8 HPDs** into tank.

20-inch High QE PMT

- Same design as R3600 used for Super-K, except for photocathode
- Precalibrate 8 PMTs in advance, installed **5 HQE PMTs** into tank.
- High QE is upgrade option for all photodetectors

QE of 8 High-QE PMTs at Kamioka



Proof test in a 200-ton tank

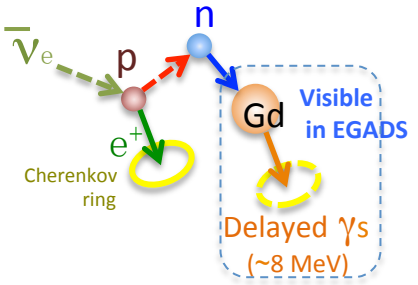
- Test new photodetectors in the 200-ton water tank.

Evaluating Gadolinium's Action on Detector Systems

200-ton test tank to demonstrate the GADZOOKS! Idea.

(**G**adolinium **A**ntineutrino **D**etector **Z**ealously **O**utperforming **O**ld **K**amiokande **S**uper!)

Anti-neutrino tagging by neutron



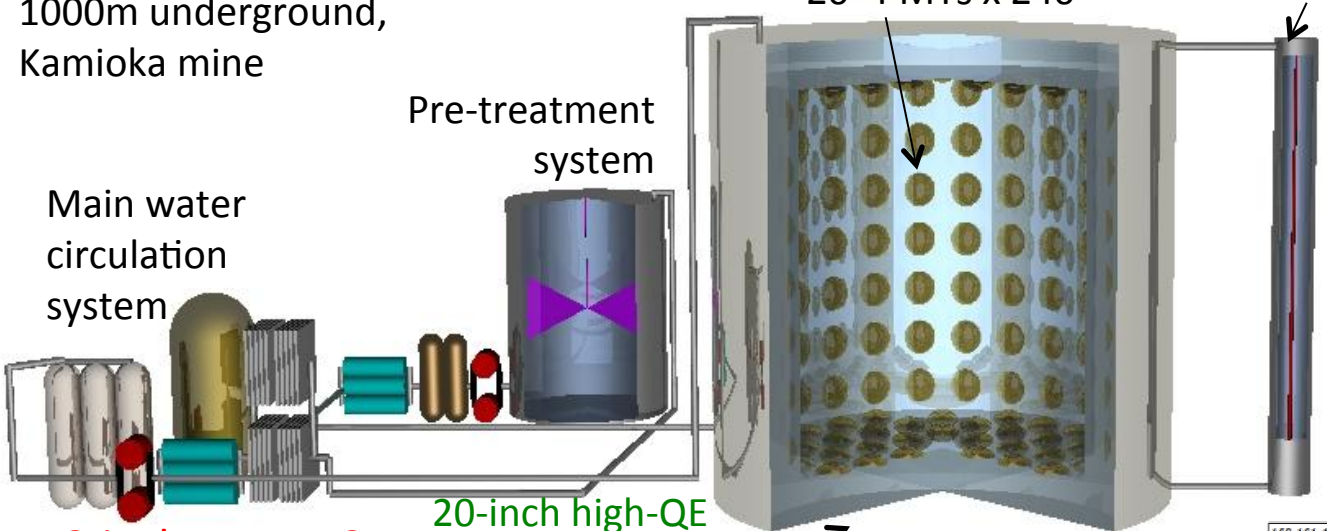
1000m underground, Kamioka mine

Transparency measurement

20" PMTs x 240

Pre-treatment system

Main water circulation system



8-inch HPDs x 8

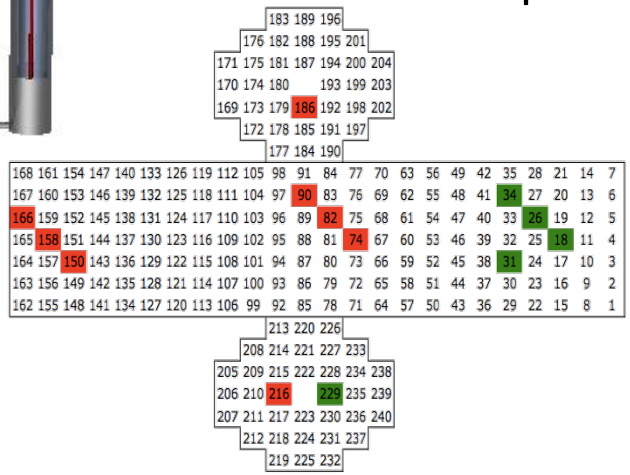
20-inch high-QE (HQE) PMTs x 5

Test new photodetectors in 200t tank

8 8-inch HPDs

5 20-inch high-QE PMTs

Compared with 227 20" PMTs used in Super-K



Installation flow in 2013 summer

Constructed floating floor on water

Cabling in tank

Installation

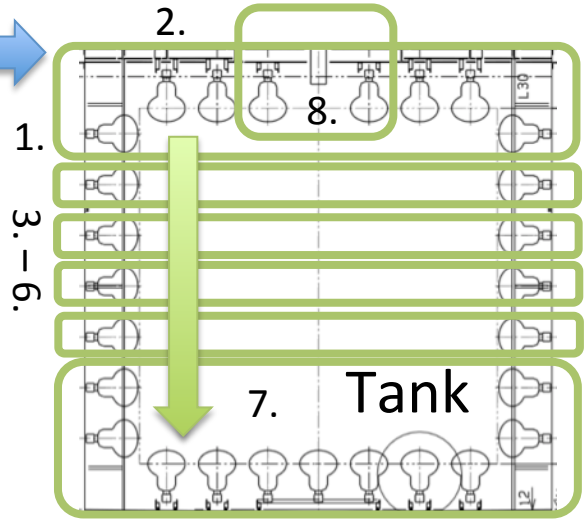
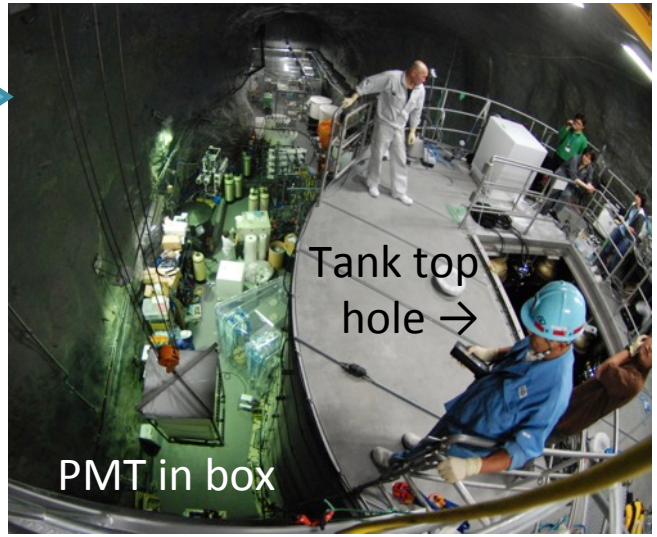


Photo-detector assembly



PMT check

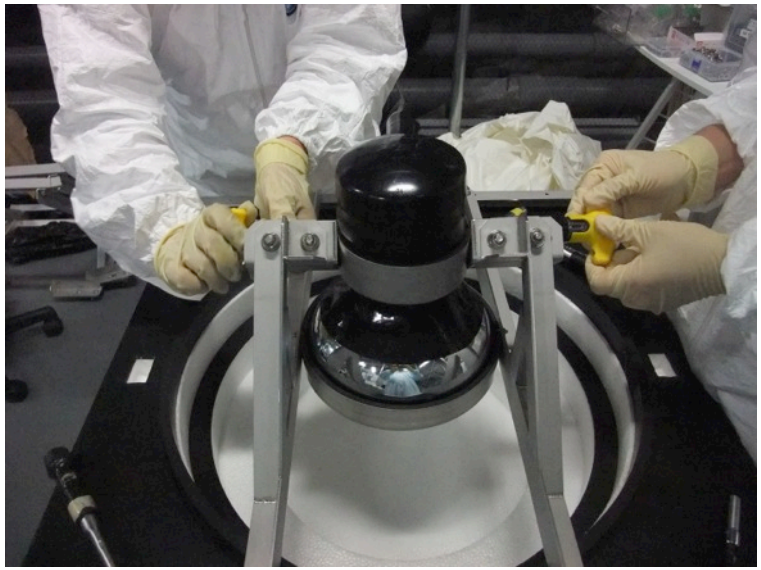
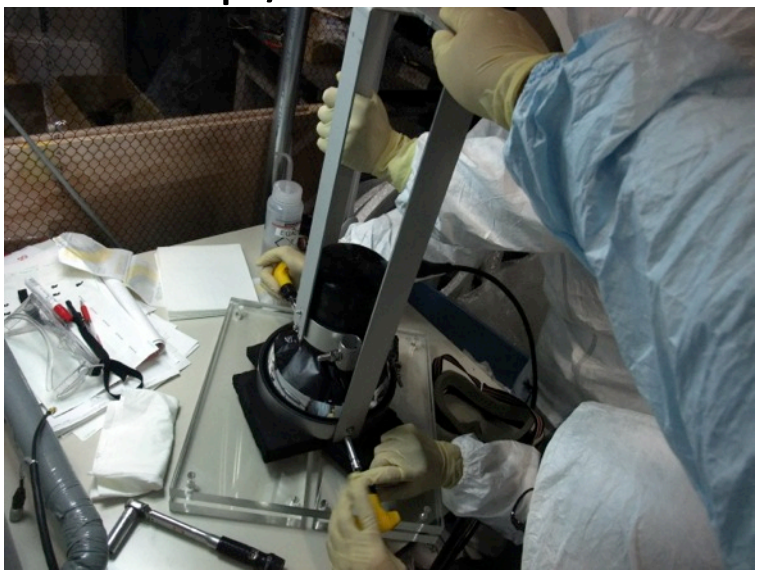
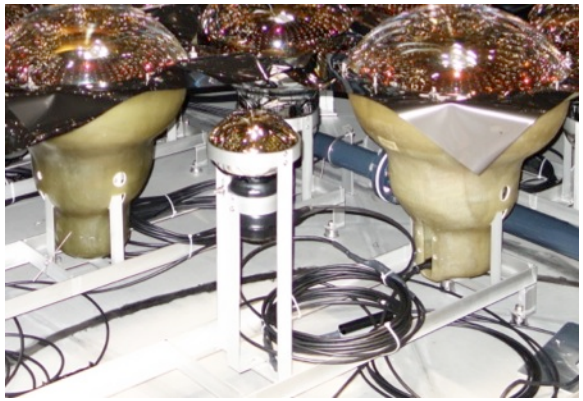
Connection check

Outside of tank

Signal check

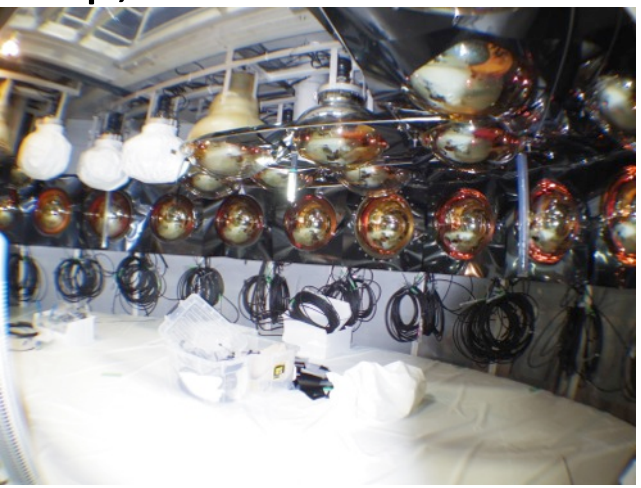
Assembly of HPD supporter

- Assembly for EGADS is based on Super-K. (NOT for Hyper-K)

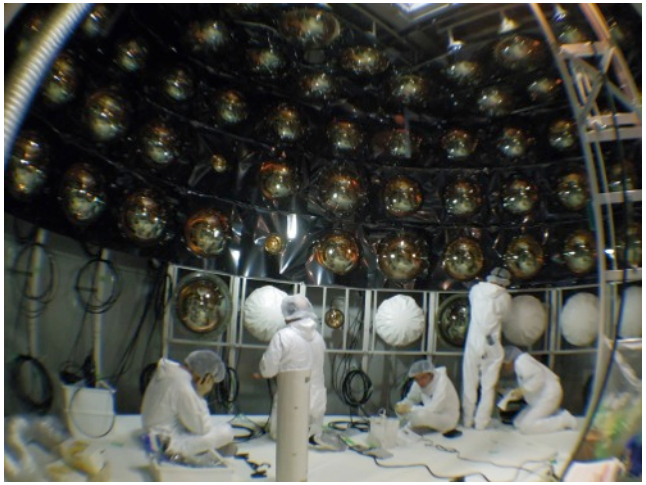
	Barrel HPD	Top / bottom HPD
Assembly		
Tank		

Installation into tank

Top, 1st and 2nd barrel

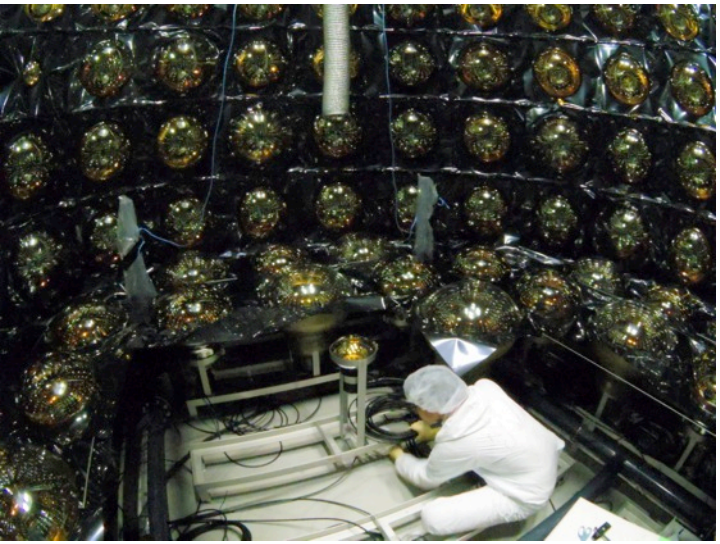


Barrel

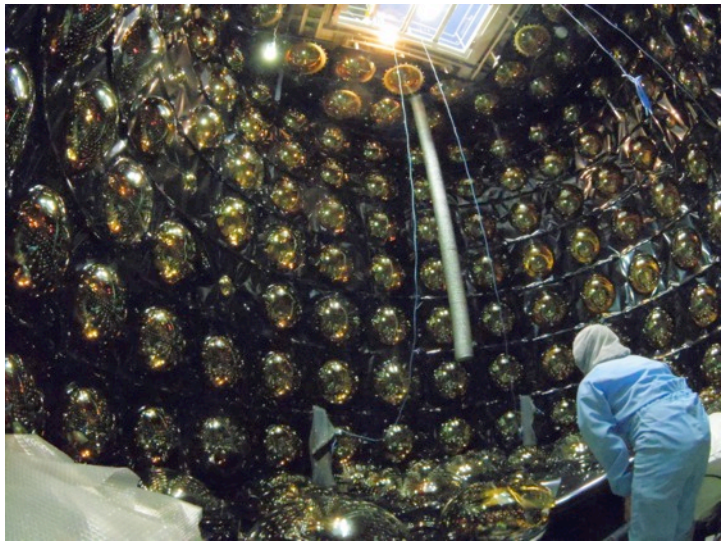


Barrel HPD

Bottom HPD



Bottom

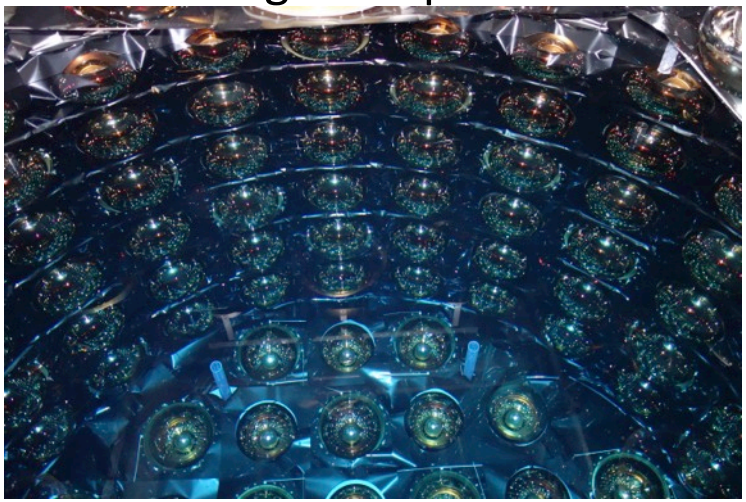


Installation from top to bottom

18 Jul – 8 Aug 2013

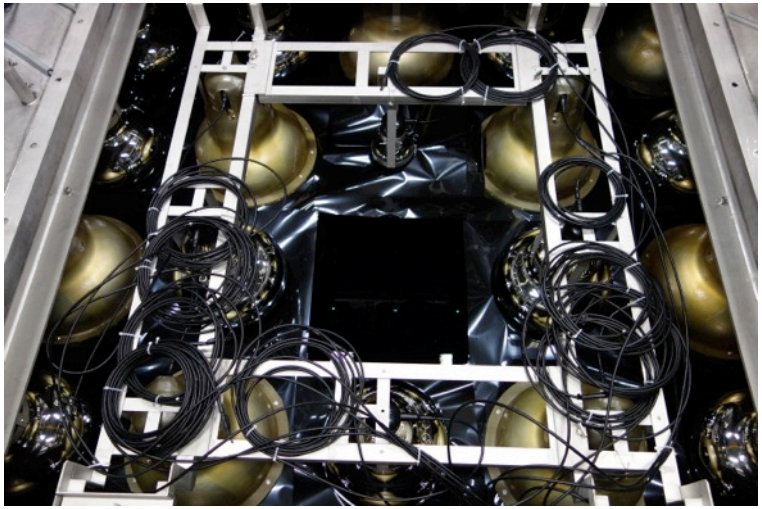
Tank closing

Water filling for top installation



PMT mounting on boat

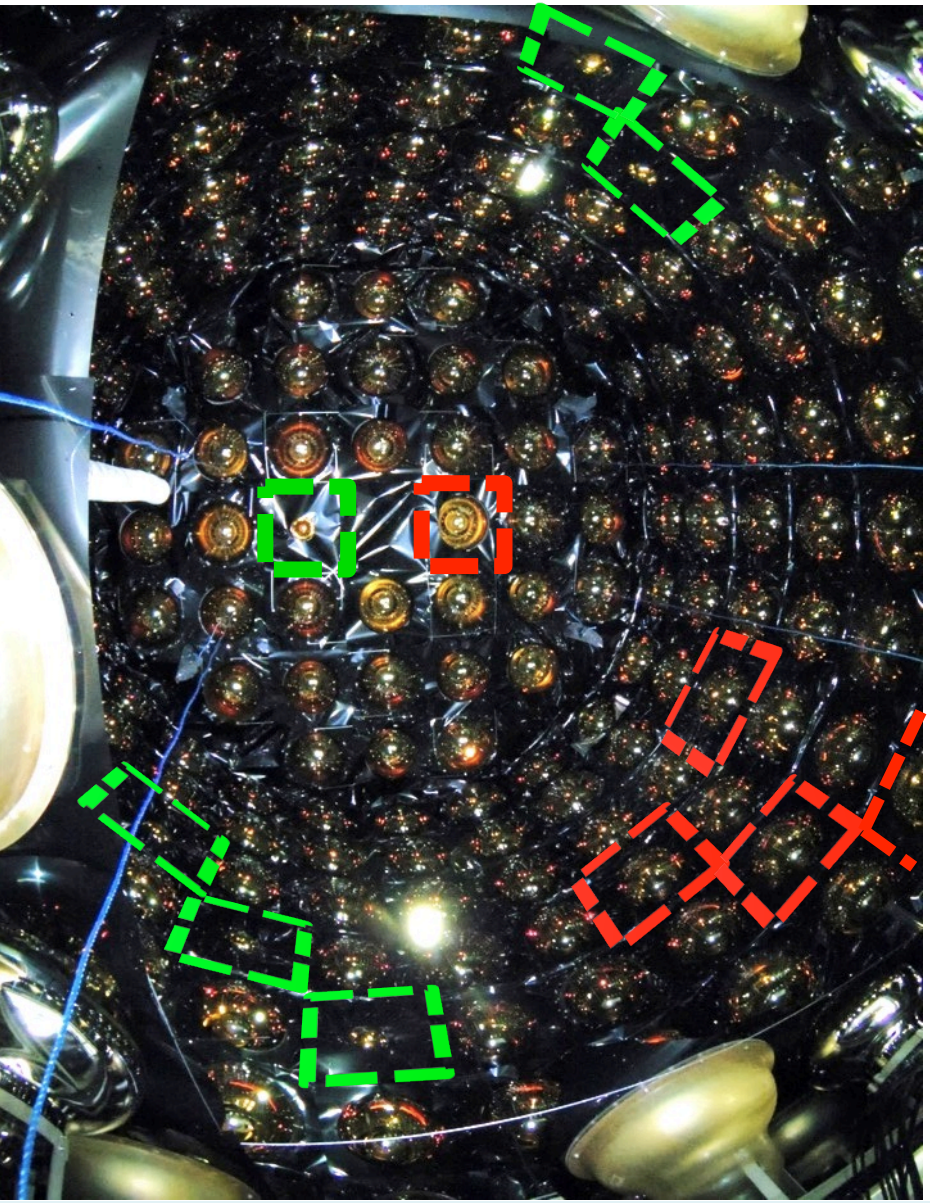
Closing hatch



Finished installation on 13 Aug.

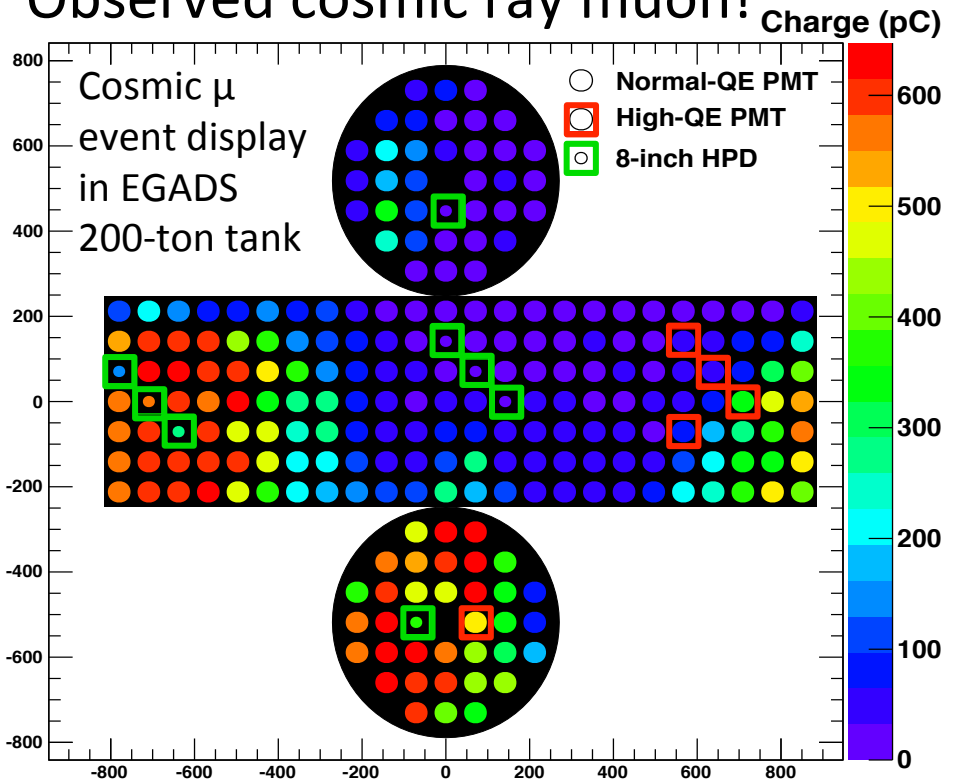
First DAQ in the end of Aug.

View of photodetectors in tank



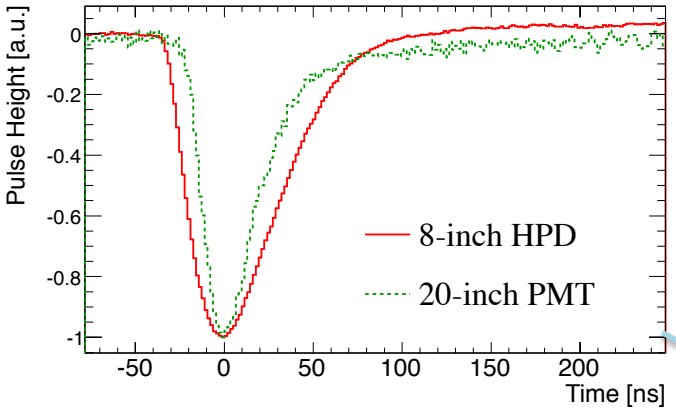
227 Super-K PMT (20”)
+ 5 High-QE PMT (20”)
+ 8 HPD (8”)

Observed cosmic ray muon!

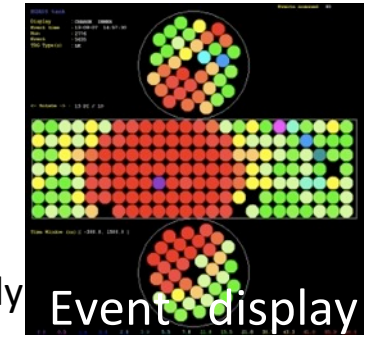


DAQ and electronics

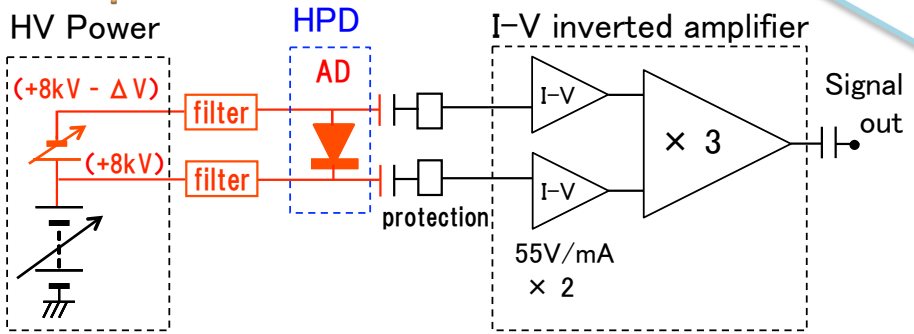
Signal from HPD, PMT



- Trigger is issued by sum of hits.
  - 1 hit = 1 HPD (PMT) with any p.e.s
- HPD/(HQE) PMT share same DAQ.
  - Because of different 1 p.e. and Q.E. level, board is prepared for these PDs separately



Preamplifier and HV - Inside of HPD -

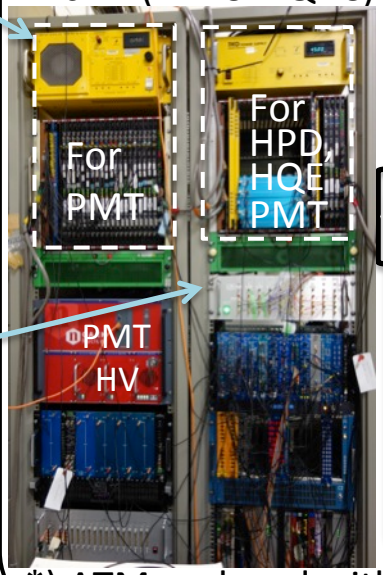


DAQ of charge + time

ATM (Analog Timing Module)

12ch x (2TAC+2QAC)→ADC

used in old SK



1 board for HPD (8/12ch)
1 for HQE PMT (5/12ch)

Trigger threshold is set **by each board (0-12mV)**

Set threshold separately (0.25p.e. in PMT case, 0.5p.e. in HPD case)

*) ATM replaced with QBEE(current SK board) later

Control Power Supply

2 Power supply lines (10V)

- For HV unit and Pre-amp. (<500mA) + GND

4 HV control lines (<1mA, 5V)

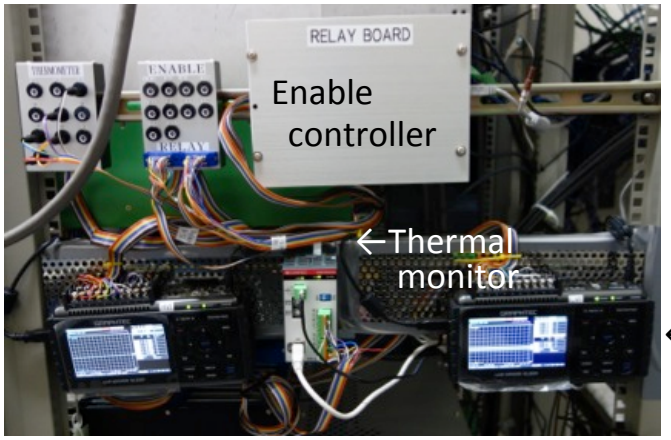
- HV control (0 - 4V out)
- AD bias control (0 - 4V out)
- Latch up monitor (+5V in)
- Enable switch (+5V out)

Slow control and monitor system

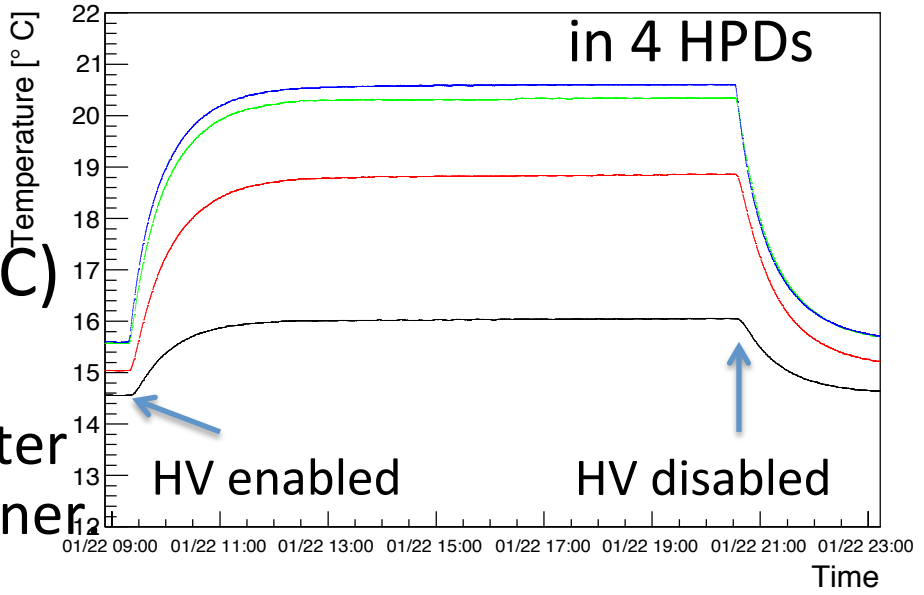
Developed by Okajima-kun

- Monitor control voltage for 8kV and AD bias, temperature in 4 HPDs, over current status, temperature around DAQ.
  - AD gain and ATM depends on temperature.
    - To study thermal dependence of HPD performance.
- Observed 2-6 ^{o}C increase in HPD compared to water (13^{o}C)
  - Take 3-4 hours for stabilization
  - Design of heat radiator into water is required in future for HPD inner

Slow control for HPD



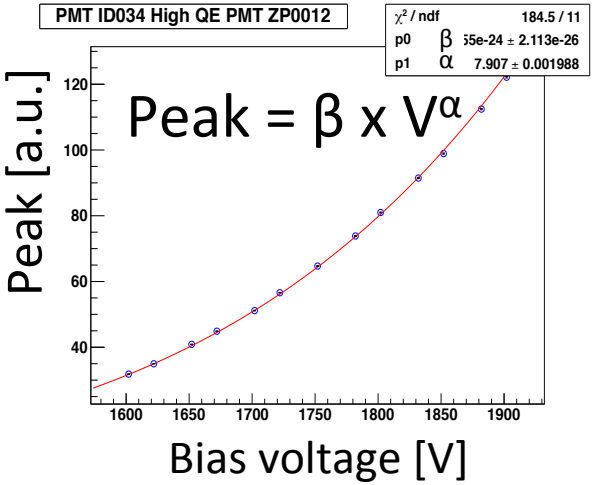
← High voltage monitor



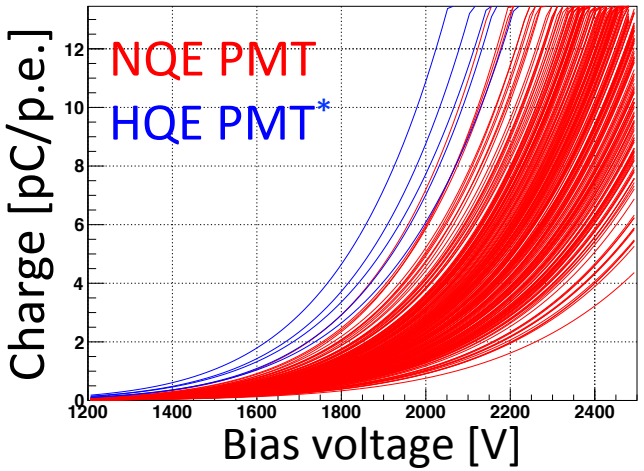
Gain calibration in tank -PMT-

- Gain of normal QE PMT is adjusted by (QE x gain) such that xenon light source makes constant peak in all PMTs.
  - Same strategy as pre-calibration in dark box before installation.
- Hit is defined by fixed 1mV for HQE PMT as well as HQE PMT.
  - High-QE (~30%) PMT is calibrated by 1 p.e. peak
    so that resolution can be comparable with R3600 (~22% QE).
  - Gain of high-QE PMT is adjusted to average gain of normal-QE PMT.

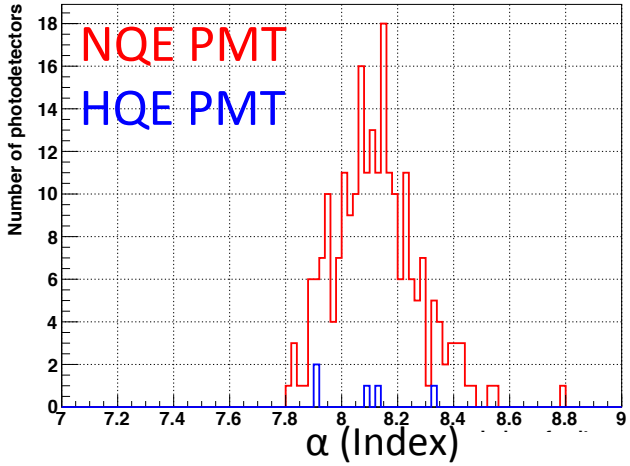
Example of HV-Gain curve



Evaluate p.e. gain for all PMTs



Fit result (Index of V)

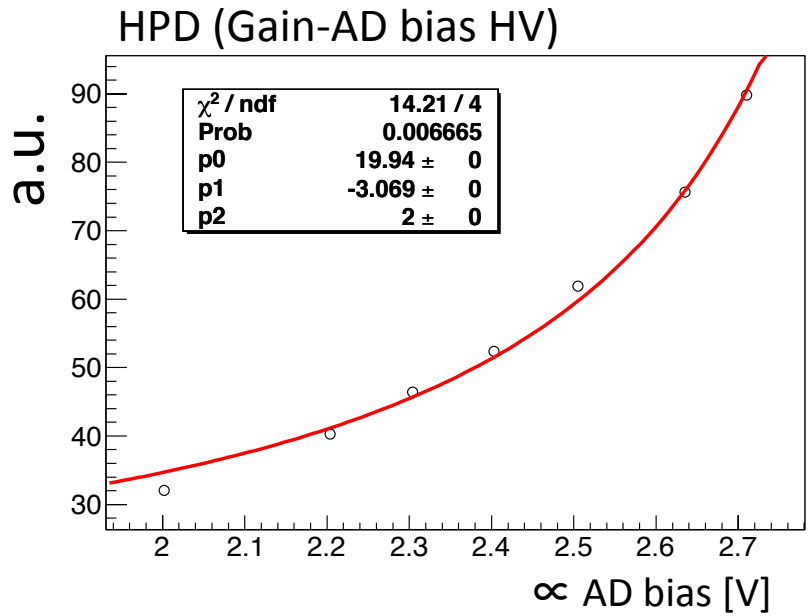


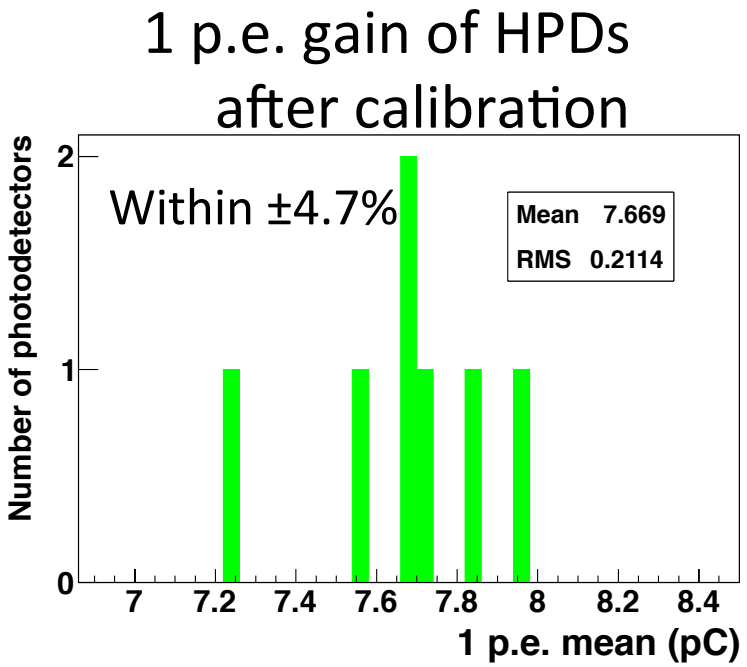
*) Higher gain of HQE PMT is due to different production date.

Gain of HQE PMT is set to ~2.2pC/p.e.

Gain calibration in tank -HPD-

- Gain of HPD was recalibrated in tank (Nov/2013).
  - Target gain is set to 7.6 pC /p.e.
    - 1 HPD gain is set to a little low level due to a low breakdown V.
  - Hit threshold is set at 4 mV (0.5 p.e.).
- Total gain is adjusted by AD bias voltage.

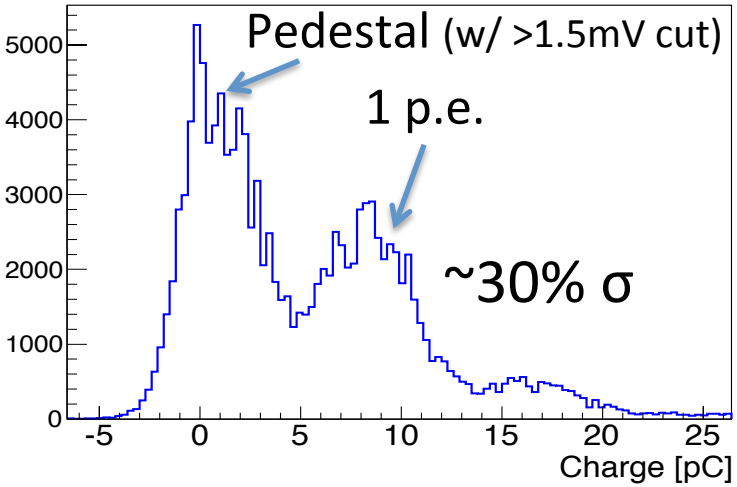




Photoelectron peak

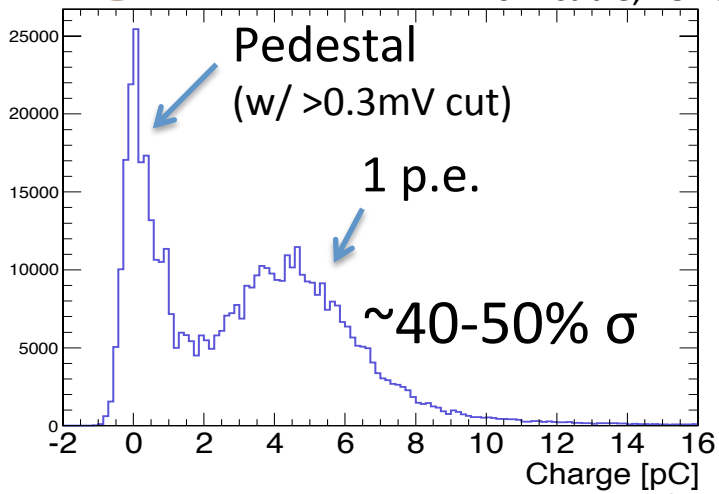
Measured with laser diode
(λ = 405nm, 500Hz),
70m cable, 13 °C in water

8-inch HPD



Threshold is usually set at ~4 mV (0.5 p.e.).
→ Broad pedestal at HPD will be cut out in actual run.

High-QE PMT

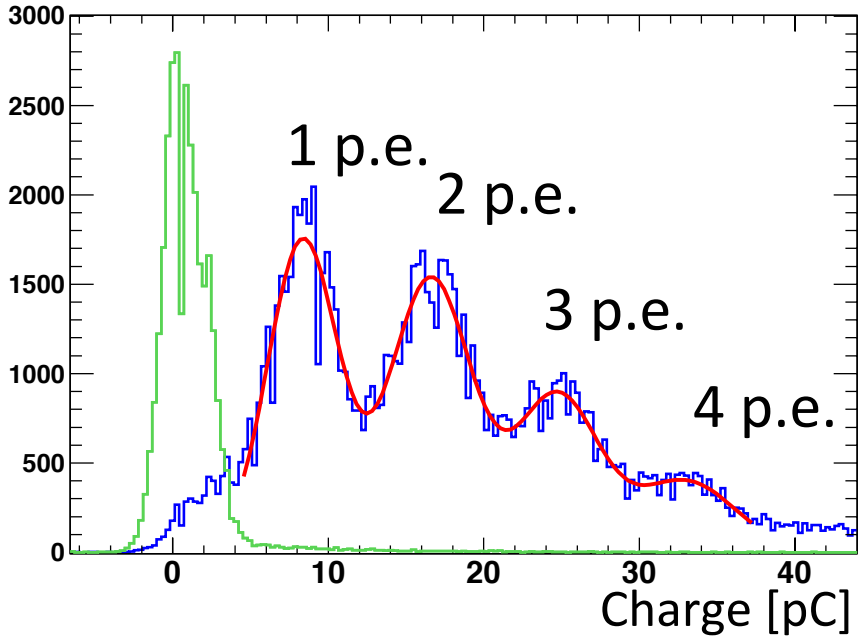


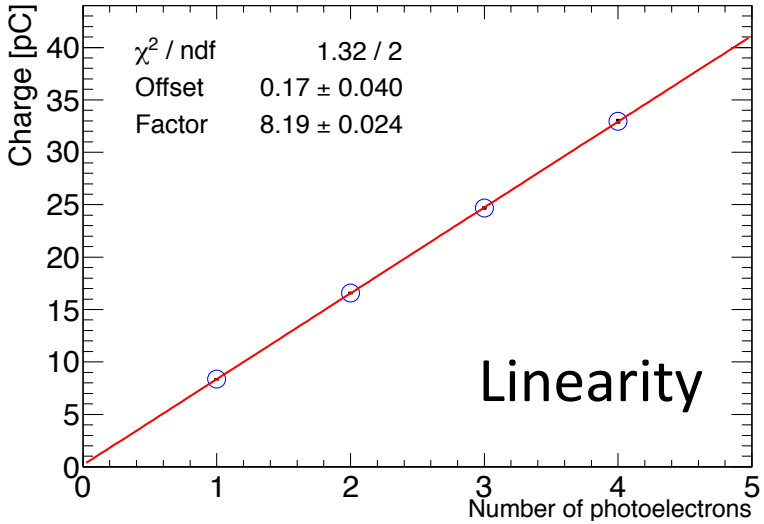
Threshold is usually set at 1 mV (0.25 p.e.).

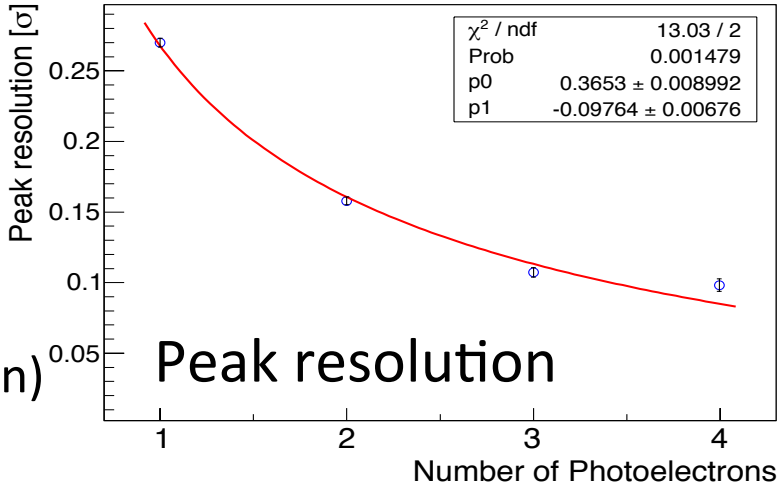
- Clear peak was observed in both HPD and HQE PMT.

Multi photoelectron peaks

8-inch HPD



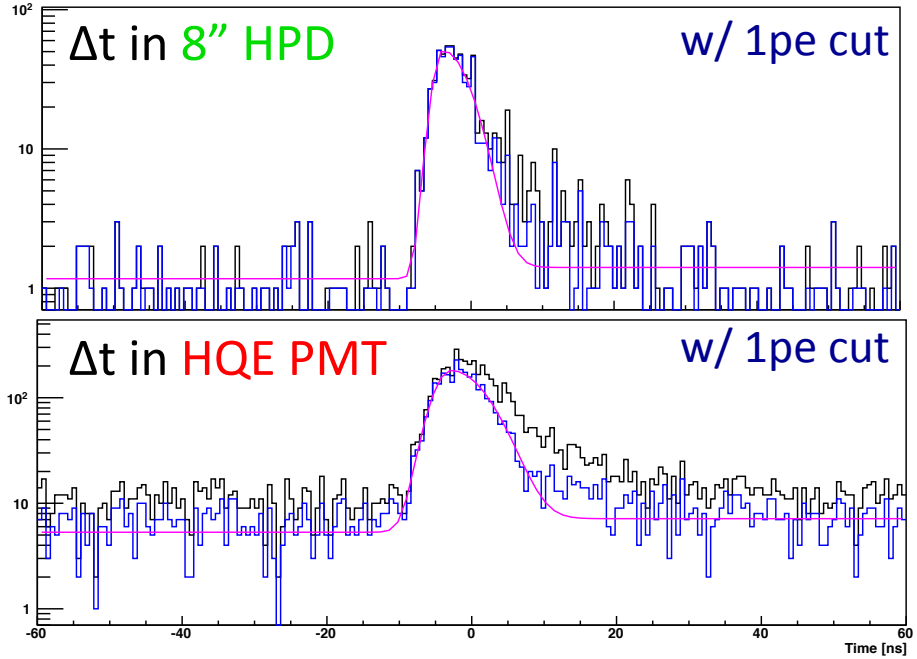


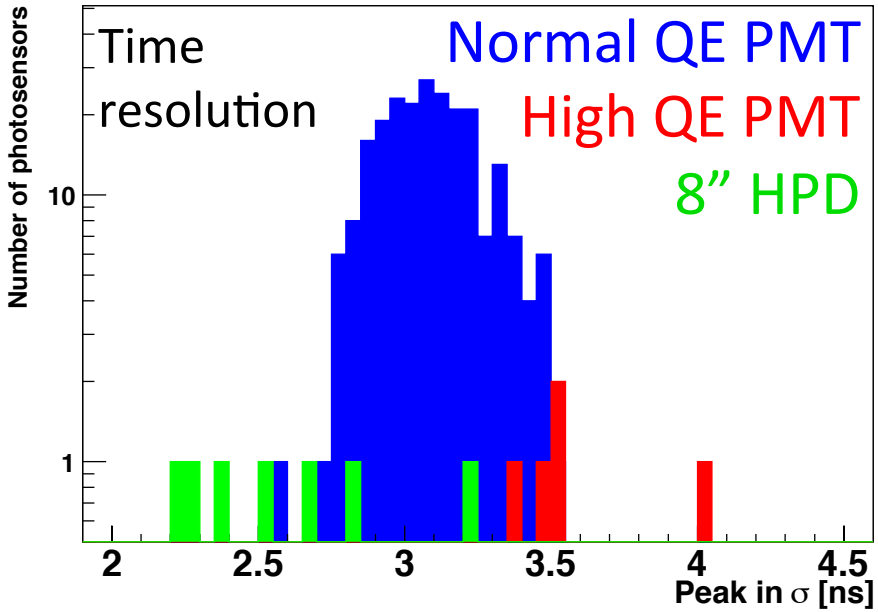


Multi photoelectron peaks
are also clearly seen by HPD.
(Difficult in case of PMT due to worse resolution)

Timing performance

- Timing resolution at 1 p.e. is measured with a laser diode.





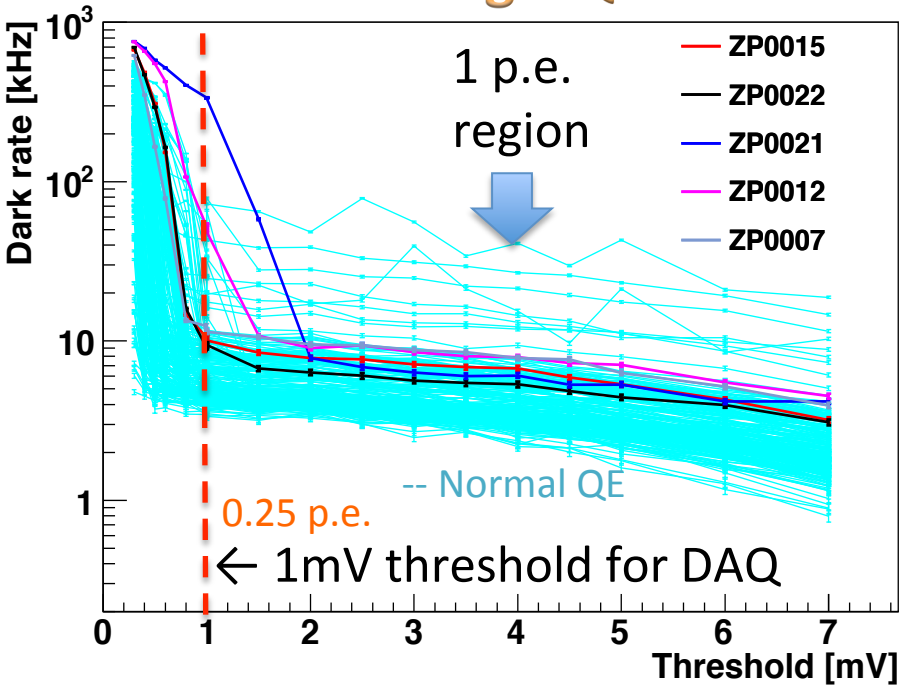
HPD shows better resolution.

- NOTE
  - Lower high voltage is applied for high-QE PMTs because of high gain level and might worse time response.
  - Time walk correction by TQ is not applied. (TQ map is under preparation.)
  - HPD time response becomes worse in preamplifier. (Upgrade in future?)
  - Time walk effect is larger in HPD due to wider signal shape.

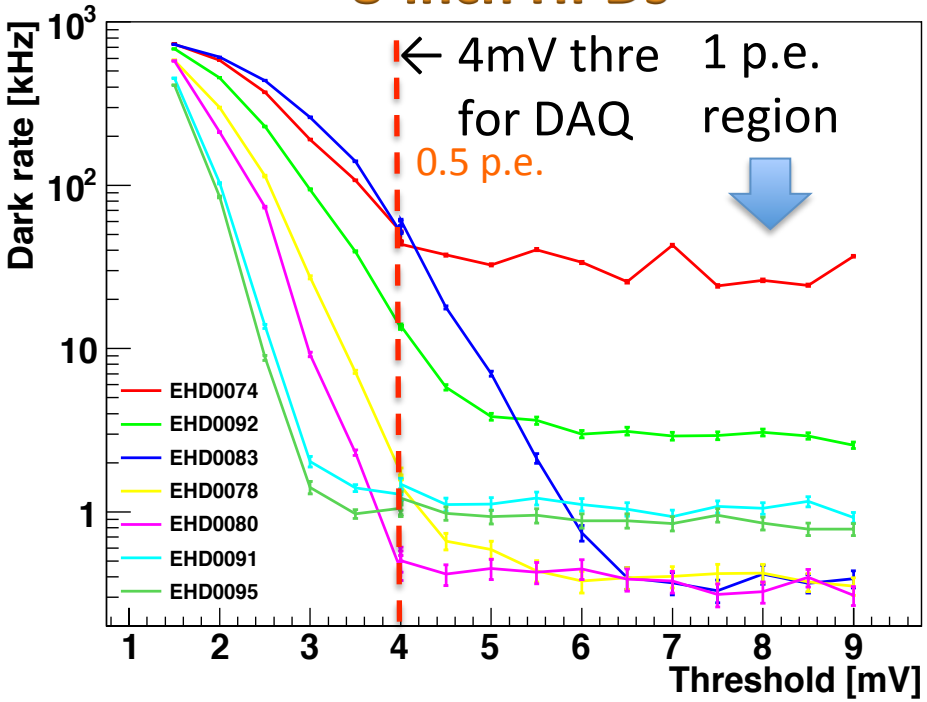
Current dark rate

- Scanned dark rate by ATM hit threshold in Jan 2014.

20-inch high-QE PMTs



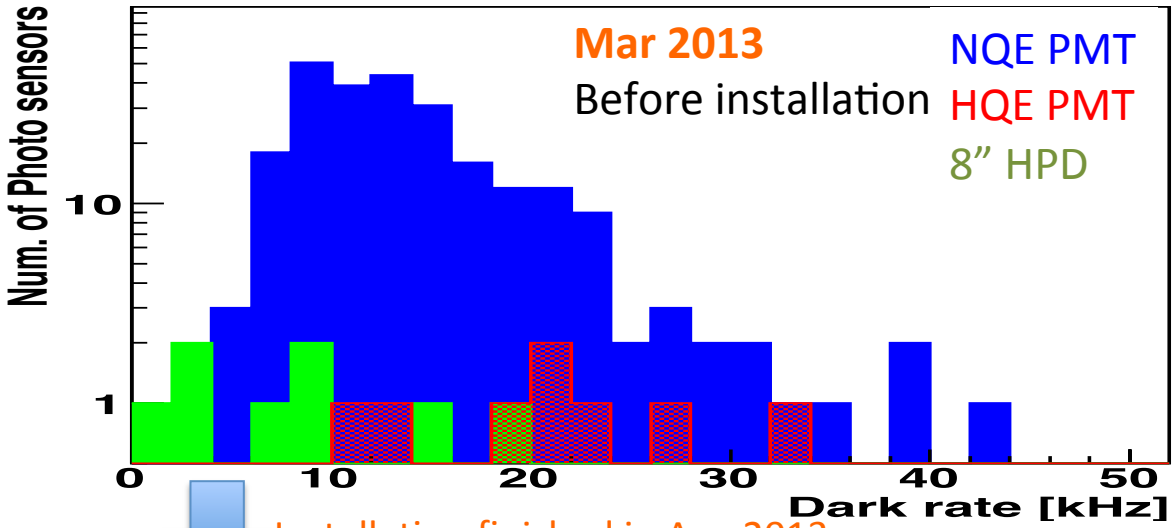
8-inch HPDs



- 2 high-QE PMTs (ZP21,12) and 1 HPD are unstable, 1 HPD has high rate.
  - Large noise around pedestal. Still under investigation and try noise reduction.
- Enough low around 1 kHz for 4 HPDs
- High-QE PMTs show a little high rate.
  - Waiting for stabilization with HV applied for a long period.

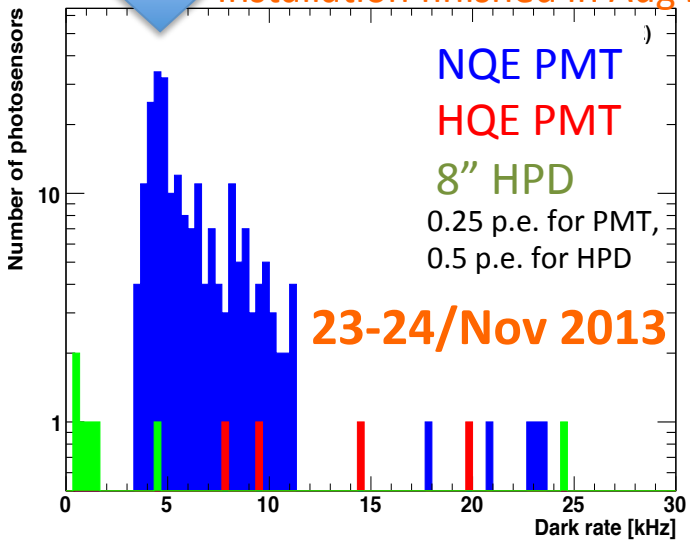
Dark rate distribution

Pre-calibration, dark rate at 0.8 p.e.

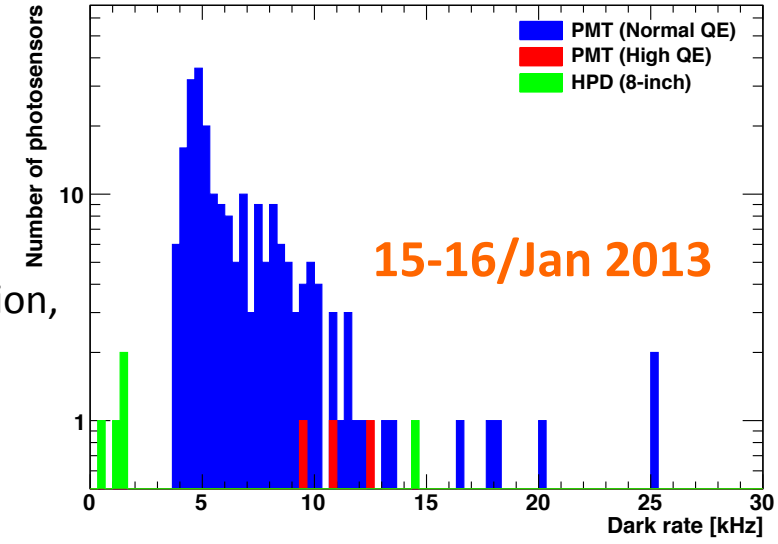


- Dark rate largely reduced after installation.
- Still waiting for stabilization after HV applied continuously from Feb 2014.

Installation finished in Aug 2013



Several calibration, measurement

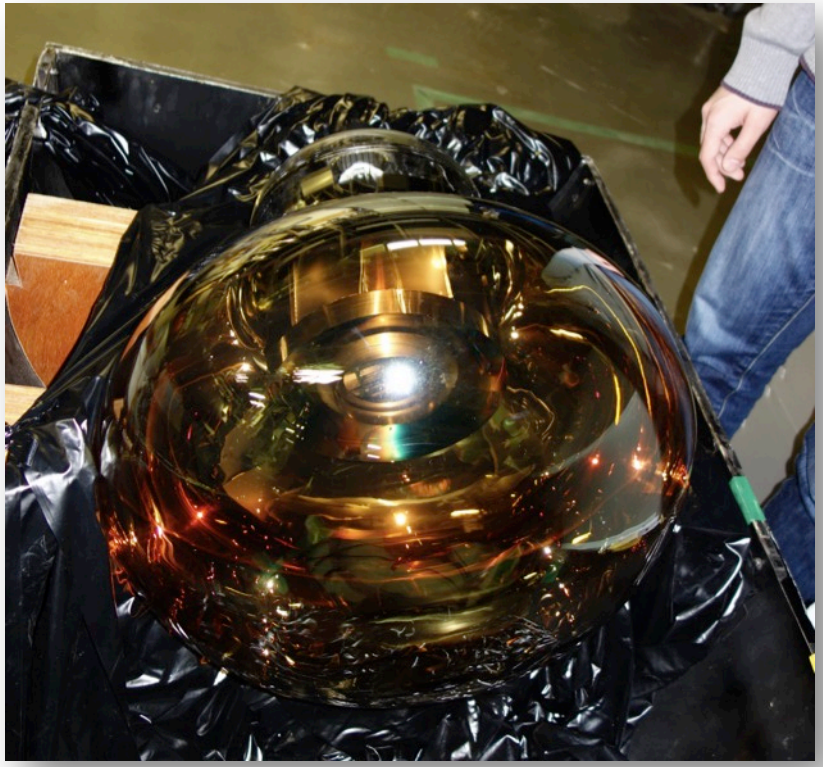


Status and plan of proof test

- Tank have been closed and filled in water since Sep 2013.
  - Photodetectors were put in dark place for 5 months.
- 1 HPD was turned off due to an over current error in HV module.
  - HV cannot be applied in a few days after tank was filled in water.
    → New HV module have been developed and upgraded.
- Dark rate of high-QE PMTs is still higher than Super-K PMT.
- High voltage was applied only during calibration and measurement.
  - Long runs were tested a few times for a few days or a week.
  - Several studies in tank such as QE, water property, TQ correction are still being performed.
- Long continuous run will start since Feb 2014.
  - Now in pure water, Gd will be doped in a few months.
    - Calibration will be redone before Gd contamination.

- New 20-inch photo-detectors are under development for 2nd proof test.

Development of new 20-inch photo-detectors



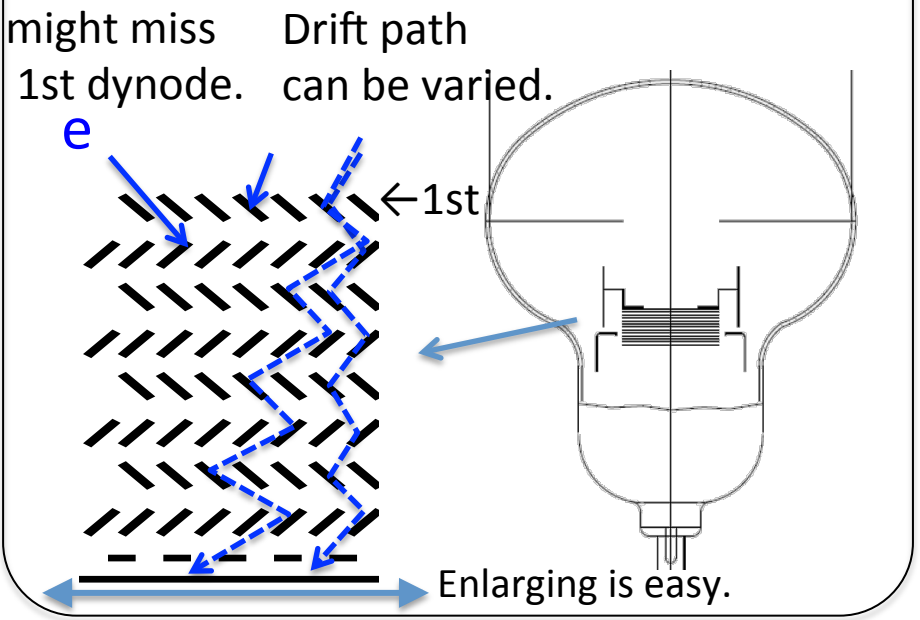
20-inch box & line dynode PMT in Kamioka

20-inch HPD display in NNN2013, IPMU

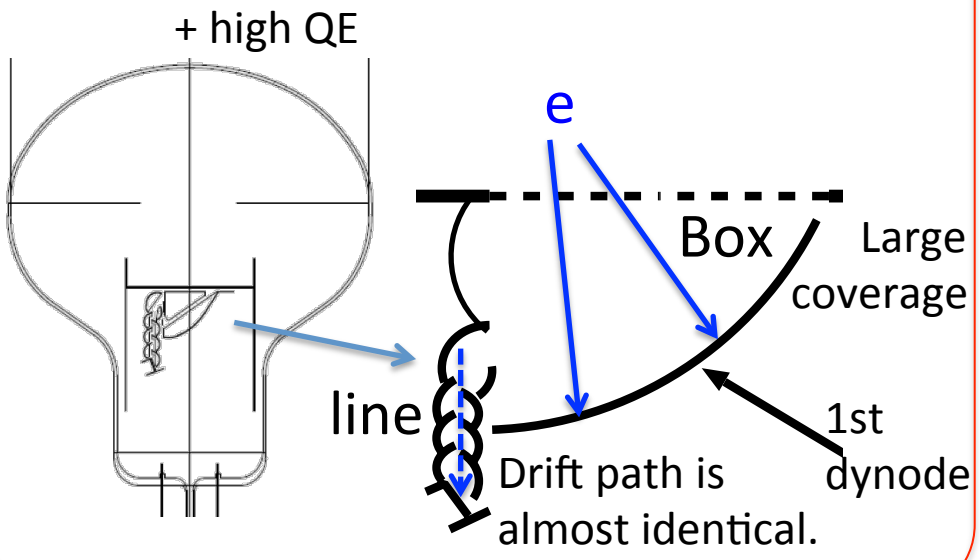
20-inch PMT with box and line dynode

- Good photon collection by box shape 1st dynode
- Fast time response by linear-focused dynode

Venetian blind type (Super-K)



Box and line type (New for 20-inch)



- New design of box and line dynode and High QE on it demands well optimizing and manufacturing process.

New 20-inch photo-detectors

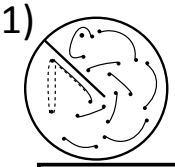
2 prototypes are under development and test in HPK.

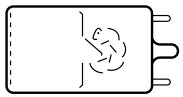
Model	R3600 (Used for ~30 yrs)	R12850 (Under development)	R12860 (Under development)	
C.E.	**80%**	**95%**	**93%**	
T.T.S. (FWHM)	**5.5 ns**	**0.75ns (w/o Preamp.)**	**2.7 ns**	Calculated in simulation
Bias voltage	**2 kV bias**	**8 kV bias, 20mm ϕ AD**	**2 kV bias**	

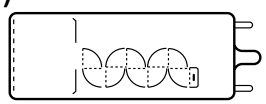
- Evaluation will start soon at Kamioka since spring 2014.
- Proof test in the 200-ton tank could start in 2014.

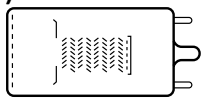
Overview of amplification designs

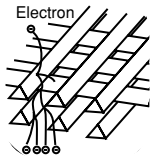
Typical value in small (~2") PMT (from PMT basics and applications, HPK)

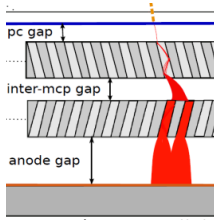
1) 

2) 

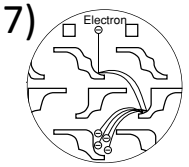
3) 

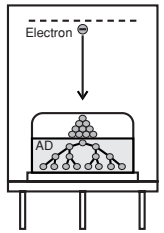
4) 

5) 

6) 

(LAPPD collab.)

7) 

8) 

	Dynode Type	Rise Time (ns)	Pulse Linearity at 2% (mA)	Magnetic Immunity (mT)	Uniform-ity	Collection Efficiency	Features
1)	Circular-cage	0.9 to 3.0	1 to 10	0.1	Poor	Good	Compact, high speed
2)	Box-and-grid	6 to 20			Good	Very good	High collection efficiency
3)	Linear-focused	0.7 to 3	10 to 250		Poor	Good	High speed, high linearity
4)	Venetian blind	6 to 18	10 to 40		Good	Poor	Suited for large diameter
5)	Fine mesh	1.5 to 5.5	300 to 1000	500 to 1500*	Good	Poor	High magnetic immunity, high linearity
6)	MCP (Microchannel plate)	0.1 to 0.3	700	1500*	Good	→Good	high speed
7)	Metal channel	0.65 to 1.5	30	5**	Good	Good	Compact, high speed
8)	Electron bombardment type	Depends on internal semiconductor →Good		—	Very good	Very good	High electron resolution

Box & Line (cf. KamLAND 17")

→ Super-K 20"

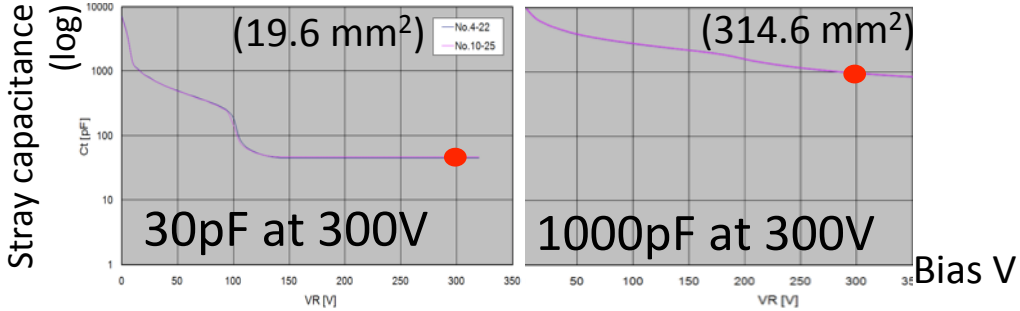
→ LAPPD

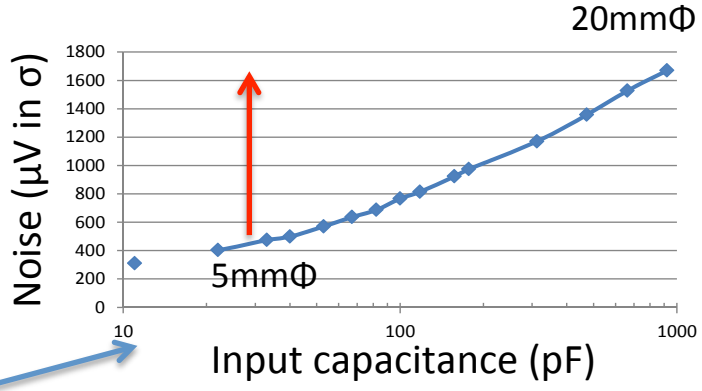
→ HPD

- **Box & line dynode PMT** : Realistic option based on established technology of PMT, with fast timing and good timing performance
- **HPD** : Low cost and good performance, but difficulty of electronics in both development and long life. → *To be established in proof test*

AD and amplifier for 20-inch HPD

- Least diameter of avalanche diode (AD) is determined by a spot size of p.e. collections and alignment precision.
  - 5mm Φ for 8" HPD / 20mm Φ for 20" HPD





  - Noise largely depends on input capacitance.
- Current pre-amp. of 8" HPD cannot be used for 20" HPD.
  - Single p.e. separation is impossible because of noise by large stray capacitance.
- Development of new amplifier started by HPK, U.Tokyo, and KEK.
  - Start from charge amp with less noise, boot strap, etc.
  - Please join us if you are interested.
- AD optimization might be needed.
  - 15mmΦ and 20mmΦ/2 segmentation were also made in test
  - Might try 3x3 segmented AD, optimize depletion layer, backside-illumination, ...

HV power supply for HPD

- Long life for tens years and quality control in production are critical in case of HPD.
  - HV and DAQ boards can be replaced on top of tank in Super-K.
  - HV module and preamp. are housed in HPD, cannot be replaced.
    - 8kV is too high to be supplied by cable in water.
    - Preamplifier is needed near to AD.
- Several problems were found in current HV module.
  - Damage of HV module by discharge in HPD
  - Damage preamplifier by large signal into it.
- New HV module is ready for new 20-inch HPD.
  - Less noise, more durability against discharge, low power, ...
- Asked several companies to develop small HV module.
- Will study with DAQ and electronics related.
  - Electronics in water for redundancy and low cost, HV cable, digitization, ...

Schedule

Goal
PD selection
for Hyper-K

Feb > Mar > Apr > May > summer > 2014 > 2015 > 2016 > 2017

8-inch HPD proof test (200 t tank)

20” HPD R&D
Evaluation in Kamioka

20” box&line PMT R&D
Evaluation in Kamioka

HPD amp, HV module development

?

Proof test of
20” HPD, box&line PMT

Test other items

Electronics in water
Photon collection

Protective case, supporter

Plan to install 20” PDs in 2014
and test for a year in 2015.

Production and test for HK prototype tank

- After R&D and proof test, photodetector for HK is determined.
- Its final design will be tested in a HK prototype tank.

Construction of HK prototype tank and final test in tank

Summary

- Eight 8-inch HPDs and five 20-inch high-QE PMTs were installed in summer 2013.
- Calibration and performance evaluation are going on in the 200-ton tank.
  - Quick look at preliminary measurement
- Long run will start soon.
- 20-inch new photo-detectors are being developed.
  - Prototype will be tested and evaluated in a few months.