

Hybrid Photo-Detector Development

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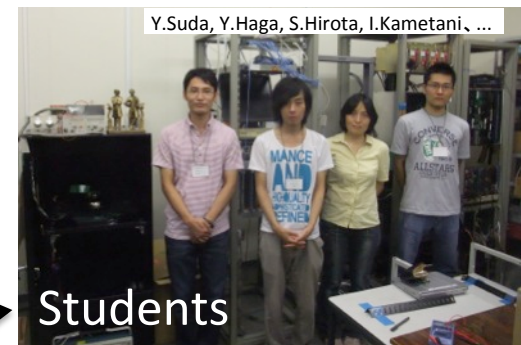


, The University of Tokyo
for the HPD group

The 2nd Hyper-K open meeting
15/Jan/2013

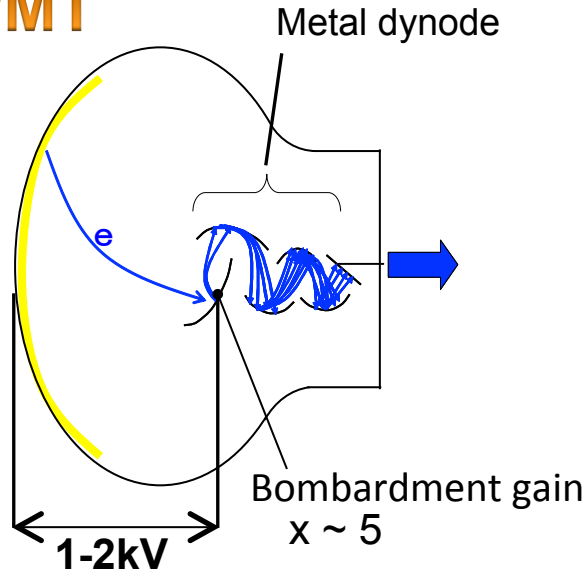
Introduction

- Hybrid Photo-Detector (HPD) is a photo sensor candidate with good performance.
- 8-inch HPD development started in May/2012.
 - 8 HPDs will be tested in a 200-ton water tank at Kamioka mine.
- R&D and proof test of 8"/20" HPDs for a few years
 - Photo sensor candidate will be determined by 2015.
- Development and preparation status of 8-inch HPD before the proof test is shown today.
- HPD R&D group:
 - Y.Nishimura,
S.Hirota, I.Kametani, Y.Suda, Y.Haga, K.Tateishi →
and S.Nakayama, H.Tanaka, M.Shiozawa, M.Yokoyama, Y.Hayato, T.Nakaya, ..
 - Y.Kawai, M.Suzuki, T.Ohmura, .. from HAMAMATSU Photonics K.K.

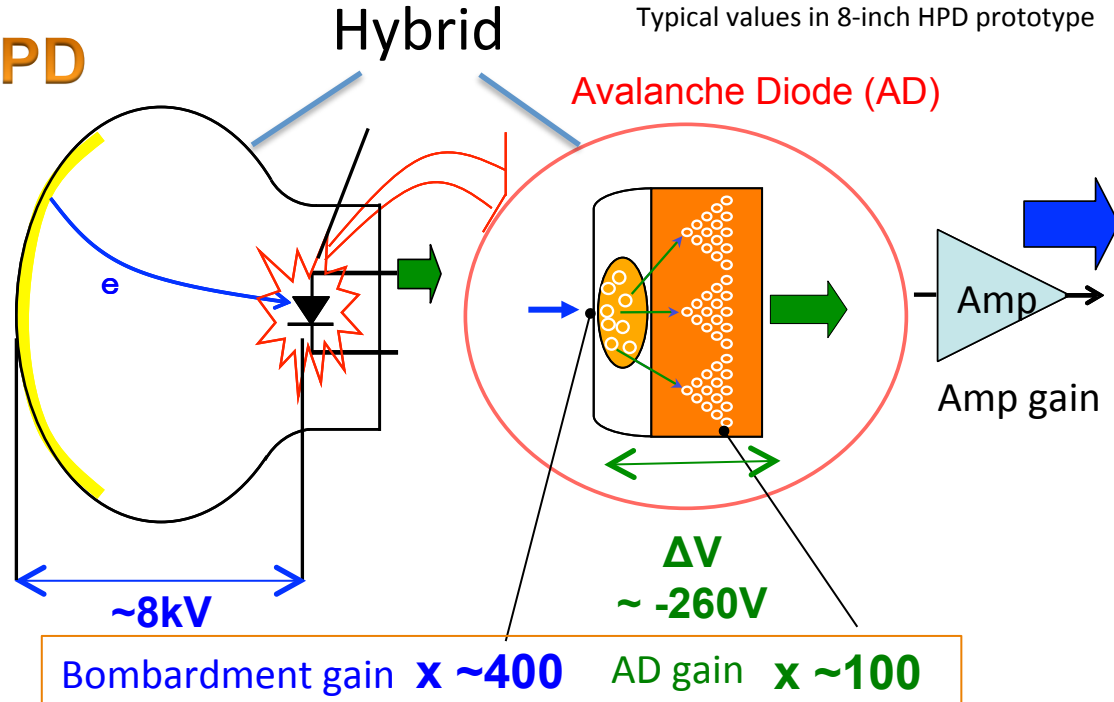


What is HPD?

PMT



HPD



	PMT (20")	HPD (8")
HV	1-2kV	$\sim 8\text{kV}$
Gain	$\sim 10^7$	$\sim 10^4 - 10^5$
C.E.	$\sim 80\%$	$\sim 97\%$

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

Proof test in 200-ton tank

Evaluating Gadolinium's Action on Detector Systems

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

(Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande Super!)

1000m underground,
Kamioka mine

Pre-treatment
system

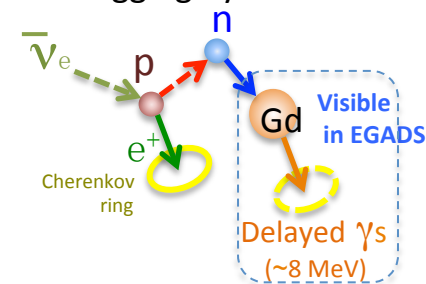
Main water
circulation
system

0.2% Gd water
in ~200 ton water tank

20" PMTs x 240

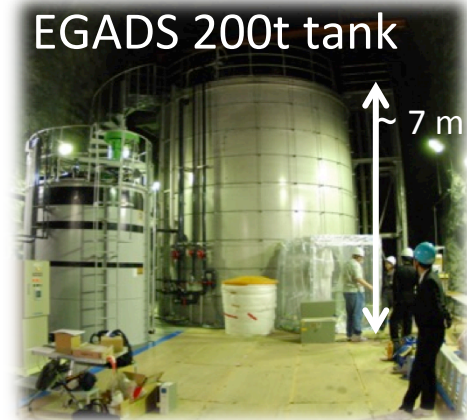
Transparency
measurement

Anti-neutrino tagging by neutron



EGADS 200t tank

7 m



8-inch HPD
and
20-inch PMT



- Install eight 8" HPDs at first proof test

- Replace several 20" PMTs with Hyper-K PD candidates during EGADS experiment

*By much help of
EGADS group*

Contents

**Development of HPD
with Hamamatsu photonics
at Kamioka
at Hamamatsu**

Check before starting production

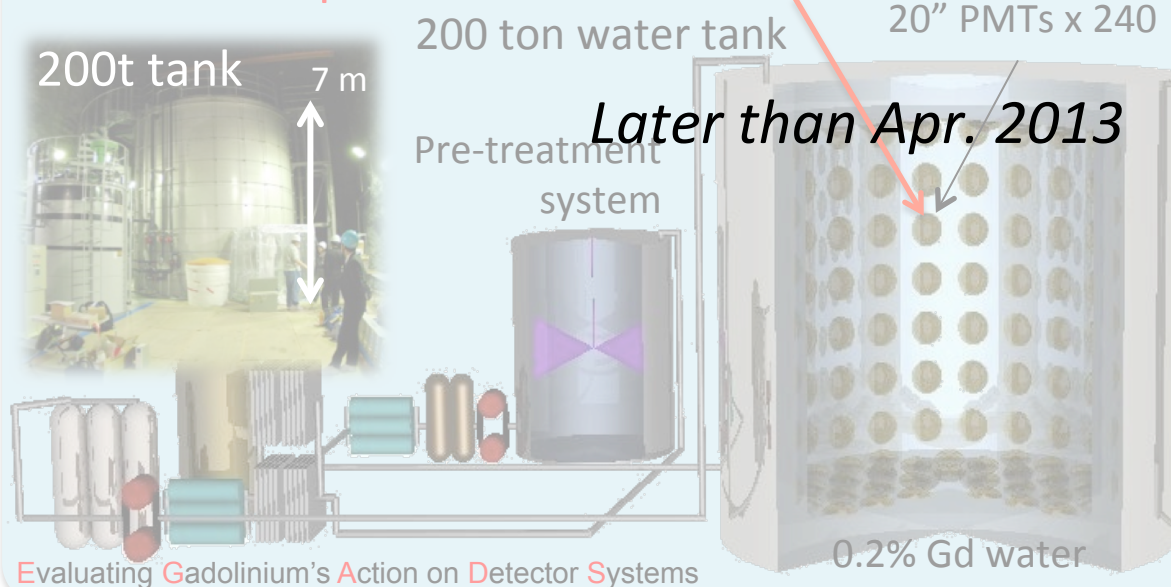
**Long running test
HV switching test**

at Kamioka

Safety test in water

at Kamioka mine

Proof test in EGADS tank (2013 -) at Kamioka mine
8 PMTs are replaced to 8-inch HPDs



8 HPDs

Install

Calibration (March 2013)

Gain adjustment
of 10 HPDs
at Kamioka mine

2 HPDs **Since Apr. 2013**
**Precise performance
evaluation**

2 HPDs are
evaluated in dark box.

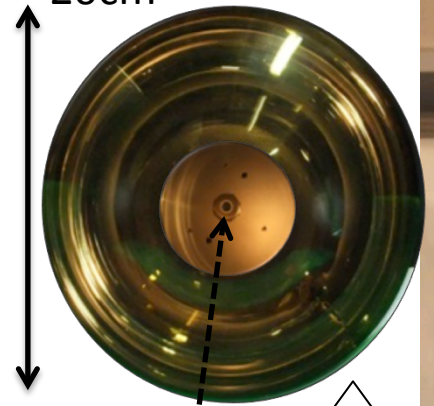
● 20" HPD and High QE R&D status, schedule

8-inch HPD

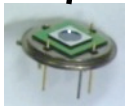
30cm

8-inch photocathode

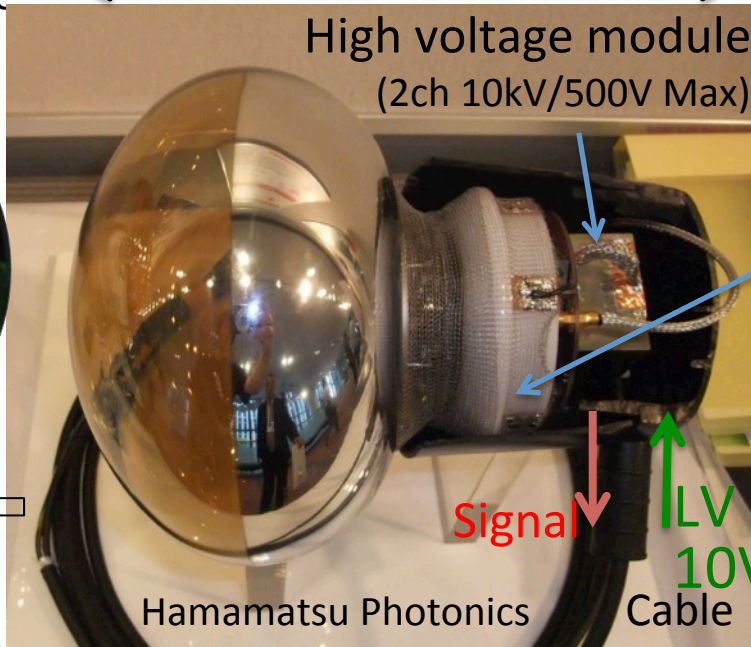
20cm



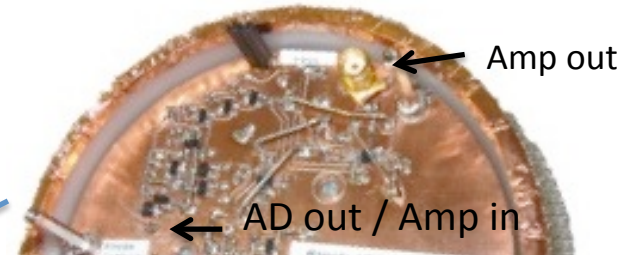
5mm ϕ



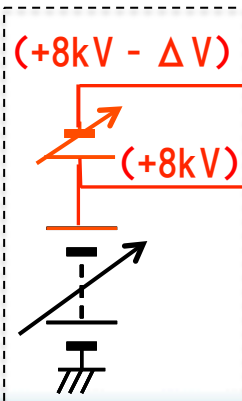
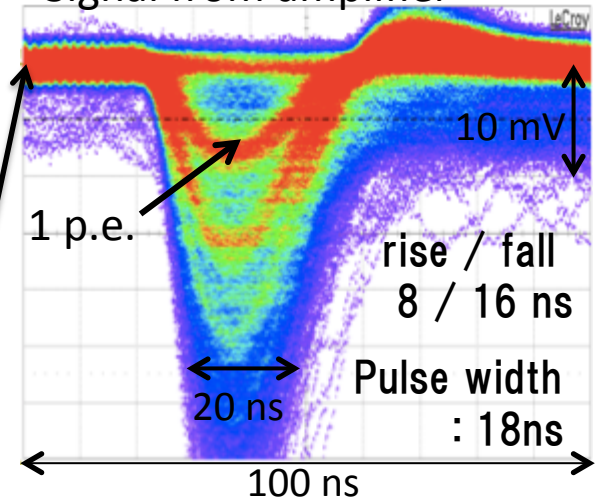
avalanche diode (AD)



Preamp
(under development)

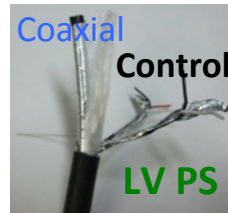


Signal from amplifier



No HV line in water!

5V \leftarrow 10V

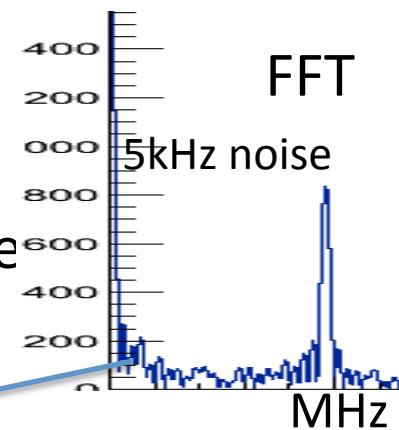


10ch control power supply



Recent progress of HPD development

- HPD module has noise from AD and amplifier.
 - Narrow p.e. peak, but broad pedestal data.
 - Electronics inside of HPD module is sensitive to noise (AD, HV, amp., ..)
 - Need to reduce noise in advance.



- Noise hunt and reduction were done.
 - Cut 5kHz noise out from HV by adding filter
 - Considering ground shield in HPD end cap.

It had been hard to see a clear 1 p.e. peak in 400ns integration time, but finally confirmed a good separation by DAQ used in proof test

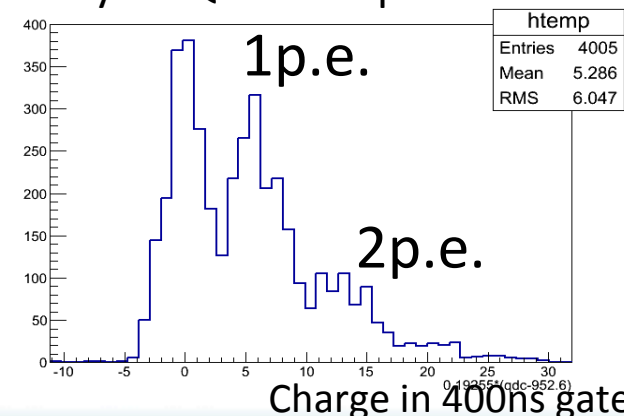
- Amplifier optimization
 - Optimize register and condenser



Suppressed ringing,
Improved S/N even
in long (400ns)
charge integration

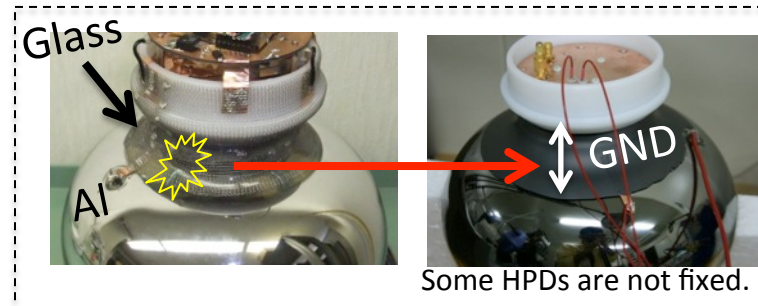
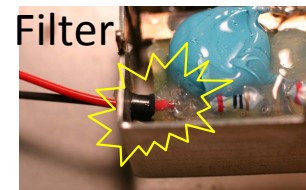


- Almost ready for production.



HV safety

- Initial version of prototype suffered an amplifier breakdown.
 - Transistor was damaged 6 times. (15/Jun, 11/Jul, 8/Aug, 8/Oct, 18/Oct in 2012)
 - During HV off → change cable connection → HV on, or changing HV, ...
- **Found and fixed ~8kV discharge by Oct.**
 - Potted noise filter for HV
(Outside of HPD on circuit board)
 - Grounding around HPD neck
(To avoid discharge inside HPD)
 - Made better HV pin connection/layout
→ Fixed
- 1 of the HPDs dropped to half gain on 10/Jan/2013.
(after 3months from last breakdown.)
 - One pre-amplifier might be broken. (under investigation)
 - Amp. optimization (soldering parts) and 10kV operation before it happened.
 - During switching HV off, disconnecting cable and HV on. (2 cables were broken.)
 - Setup was unstable, but still need to take care of such an accident..



Test toward HPD proof-test

- We tested 5 HPDs at Kamioka.

- 1 water-proof HPD, several types of amplifier, etc.

3 checks were done in 2012 to avoid breakdown in 200-ton tank.

- Long running test at least for a few months

- To avoid sudden breakdown, rapid decrease of gain, etc.

- Demand no breakdown over a month.

- Long HV module life and no amplifier breakdown by HV

- Most breakdown occurred between HV off and on.

- Demand 30,000 times switching.

- ▶ Assume 2 times / day x 5yrs x 8 HPDs

- Safety HPD operation in water

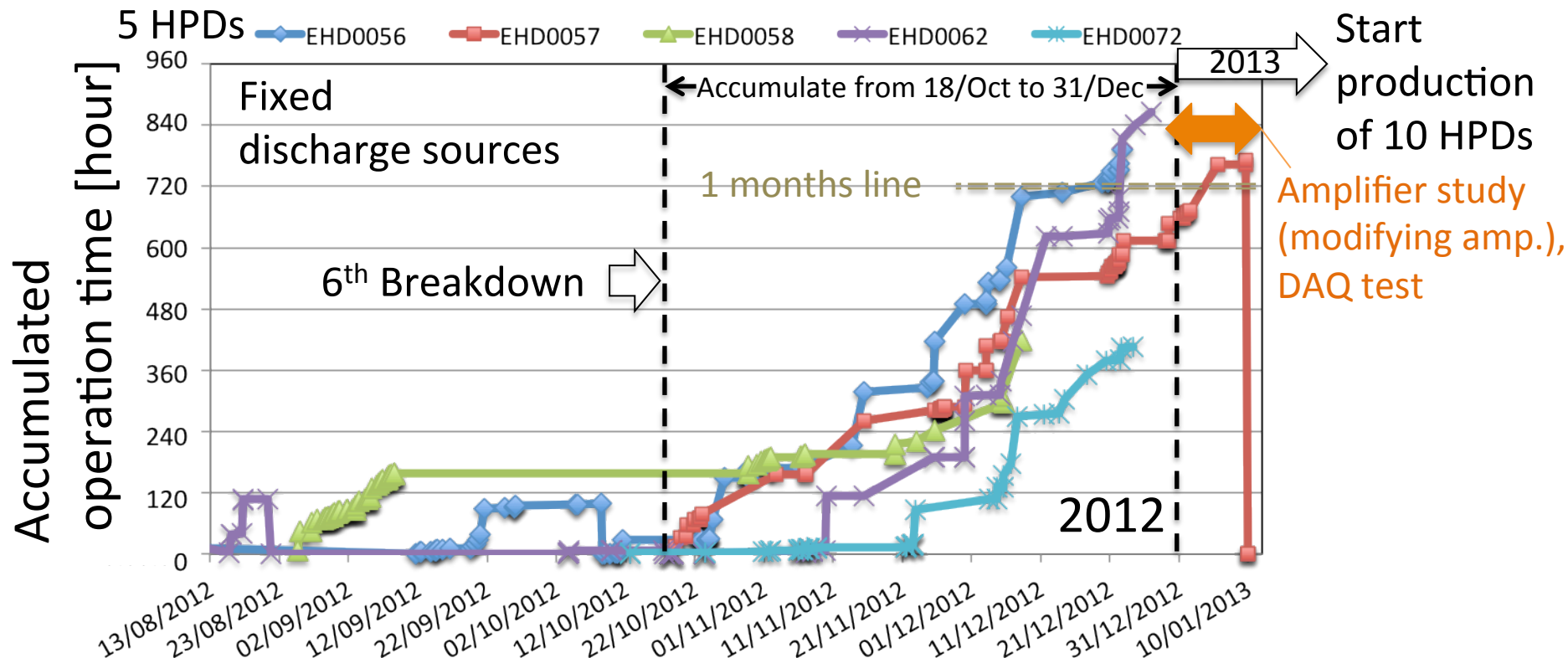
- Material is same as Super-K PMT and there is no conductivity outside of HPD.

- Test HPD in water and check no electronic/light leak.

Test before starting production of 10 HPDs in Jan 2013.

Long running test

- Demand no breakdown over a month by the end of 2012.



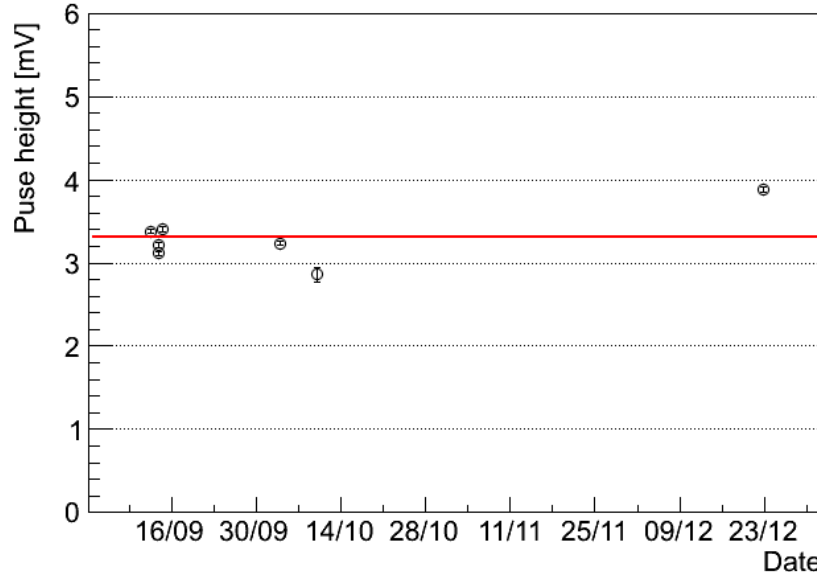
- So far, 1 HPD is alive for 847h (35 days) at maximum.
- In total, 127 (days x HPD) by the end of 2012.

Pulse height history at 1 p.e.

- No drastic change for ~ 3 months (Within $\pm 10\%$ level)

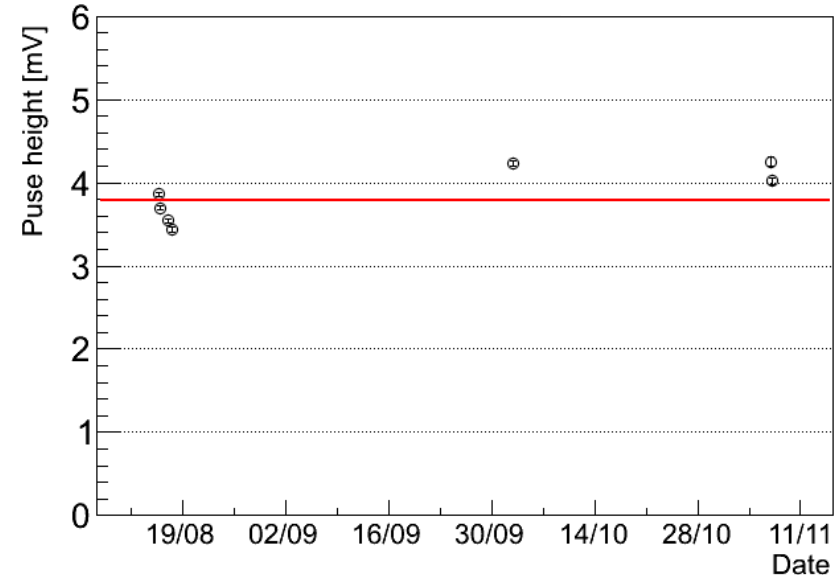
1 p.e.

EHD0056



1 p.e.

EHD0062

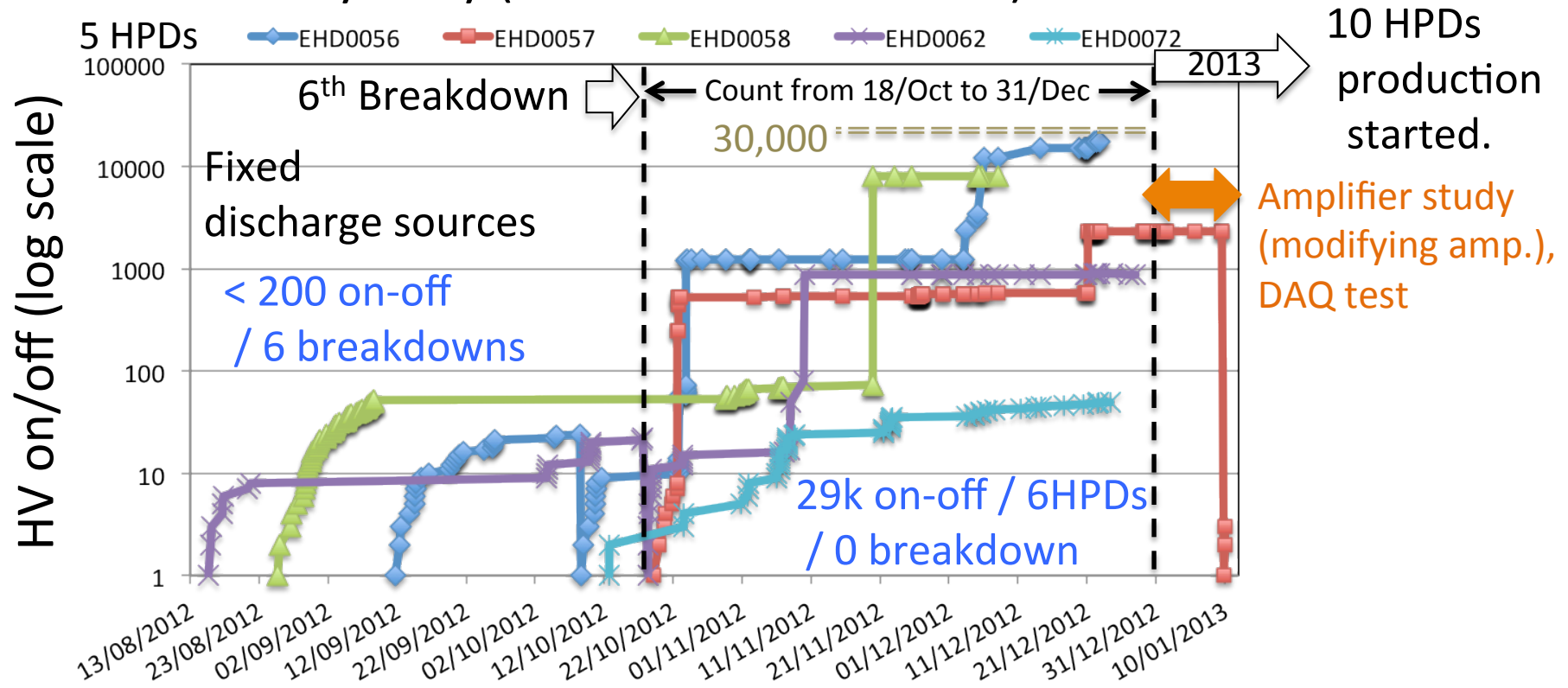


- Systematic uncertainties are not included.

- Setup changes
- Different noise, grounding
- AD gain depends on temperature.

HV switching test

- Check durability by switching HV (300V, 8kV) on/off many times.
- Automated by relay (7sec ON and 8sec OFF)



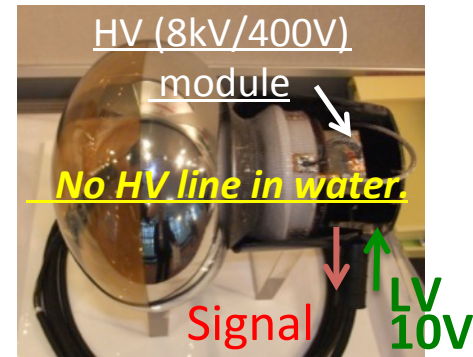
- Demand 30,000 times switching (2 times / day x 5yrs x 8 HPDs) by Dec 2012.
- 28996 in total (17693 at max. in 1 HPD)

- Tests finished w/o problems, and production started from Jan 2013.

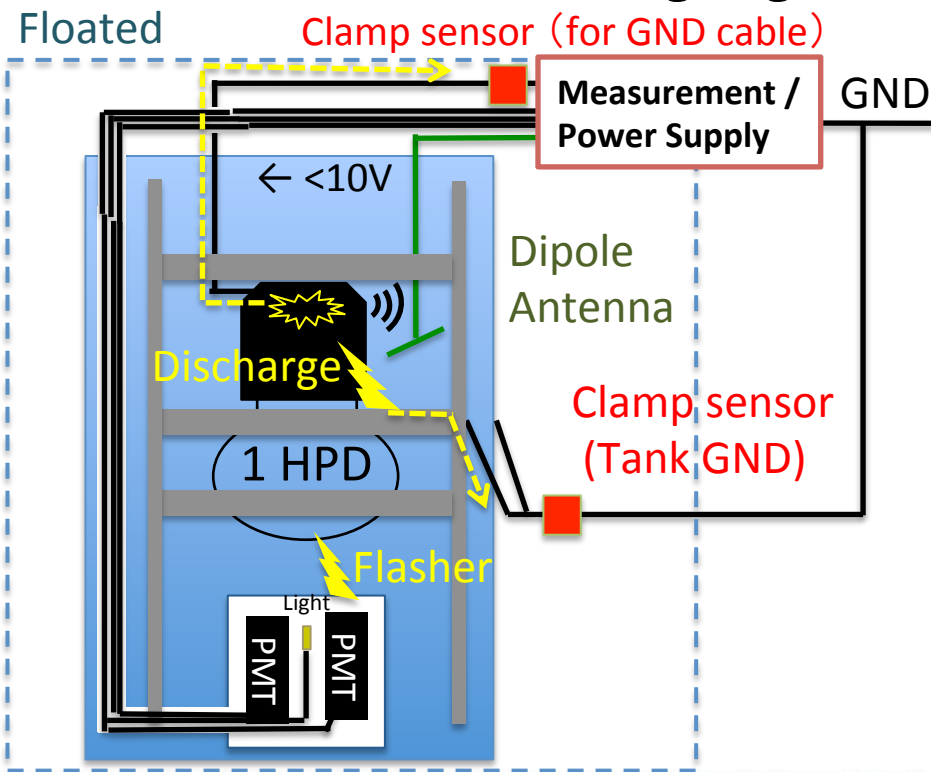
HPD safety test in water

- Purpose of water test is to confirm the following:
 - HPD works properly in water (even if Gd is loaded)
 - Safe and stable operation without any damages

This time only for EGADS proof test
 Test 1 HPD in water → in Gd water → 10 HPDs in Gd water



Schematic view to detect charge/light leak



Test for discharge inside HPD to confirm amp and DAQ safety

- Leak through cables detected by clamp sensor
- Electric wave detected by antenna

Test for discharge to water, to confirm safety of things in tank (PMTs, etc.)

- Detected by tank GND monitor by clamp sensor
- Light monitor by 2-PMT coincidence

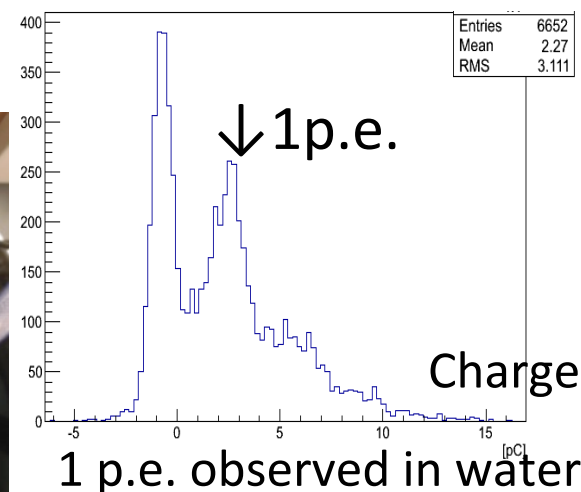
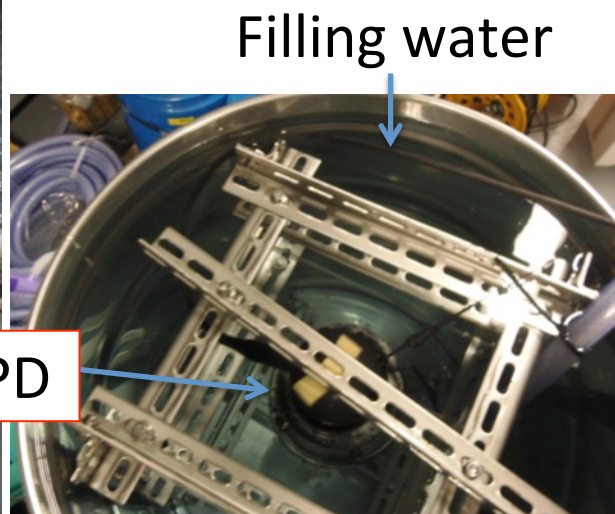
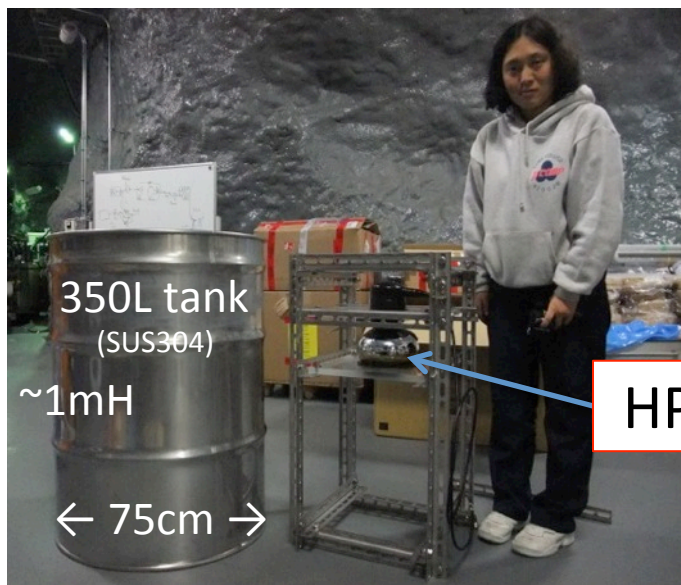
Test for flasher HPD making trigger BG

- Light monitor by 2-PMT coincidence

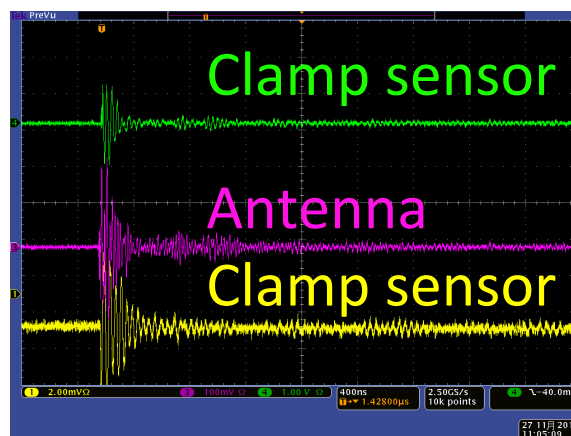
Measurement

- Calibration of discharge detectors (antenna and clamp sensor)
 - Artificial discharge in 350L water tank by condenser
 - ▶ (5kV / 8kV / 10kV) x (220pF / 1000pF) x electrode location (discharge point)
- Background run
 - HPD on/off : Exclude common external noise, flasher off from HPD
 - w/, w/o water : Cherenkov light BG for HPD and PMTs
 - PMT single rate : for PMT coincidence rate
- Triggered channel
 - PMT coincidence, HPD large signal, antenna, clamp sensors
 - Take waveform, count rate

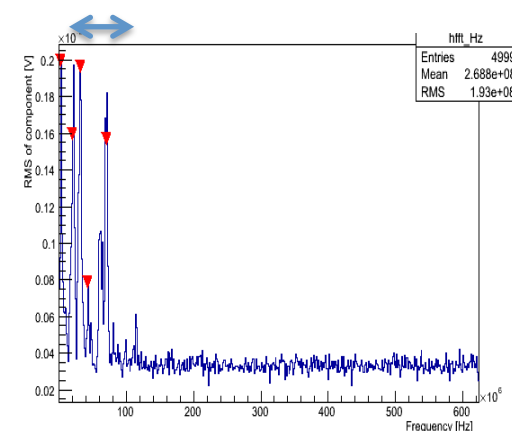
Setup and discharge detection



Detecting artificial discharge
(Calibration by condenser)



FFT shows discharge signal
around 10-100MHz



Clamp sensor
(Clipping
GND cable)

Result

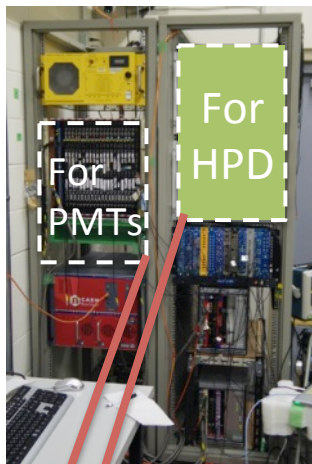
First check was done. ← Test 1 HPD in water → in Gd water → 10 HPDs in Gd water
(in Feb.) (in Mar.)

- Flasher rate (by PMT coincidence)
 - **< 0.003 Hz** (Reached sensitivity of the current setup)
 - ▶ No concern for 200-ton test in EGADS experiment
- Event rate detected by antenna
 - **~0.032Hz** (86% of events were also observed by HPD, systematic error should be excluded later.)
- Leakage from HPD to water tank
 - **0 event for 14 hours**
- Large inverted signal from HPD
 - **< 0.067 Hz**
- No breakdown of any electronics during tests.
- Discharge-like event rate is sufficiently low for 8" HPD test in water.
 - Similar test in 'Gd' loaded water will be done next month.
 - A longer safety check will be required for HK case. (together with EGADS proof test.)

For gain calibration

Production of 10 HPDs has started. Calibration is planned in Mar 2013.

DAQ of proof-test :



1 board
for 8 HPDs

ATM(Analog Timing Module)

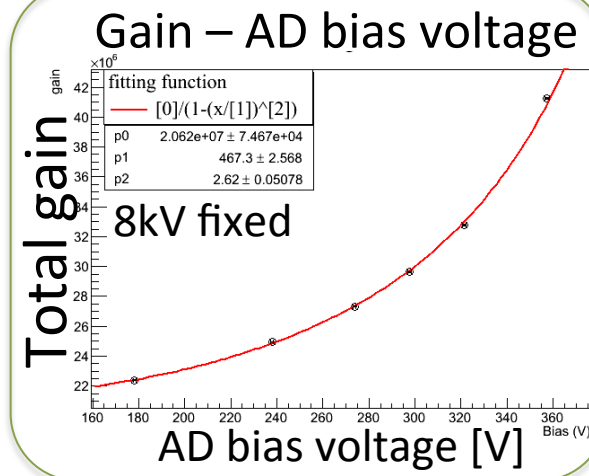
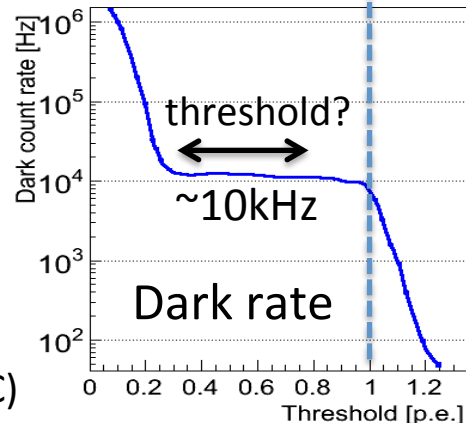
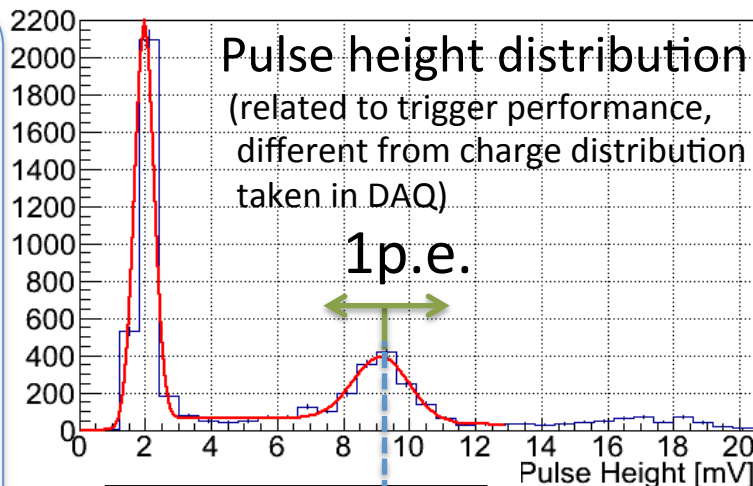
used in old SK,
in 1st year in EGADS

12ch x (2TAC+2QAC)

400ns integration range

Threshold can be set up to ~12mV,
hit rate should be less than 10kHz.

HPD threshold can differ from PMT's.

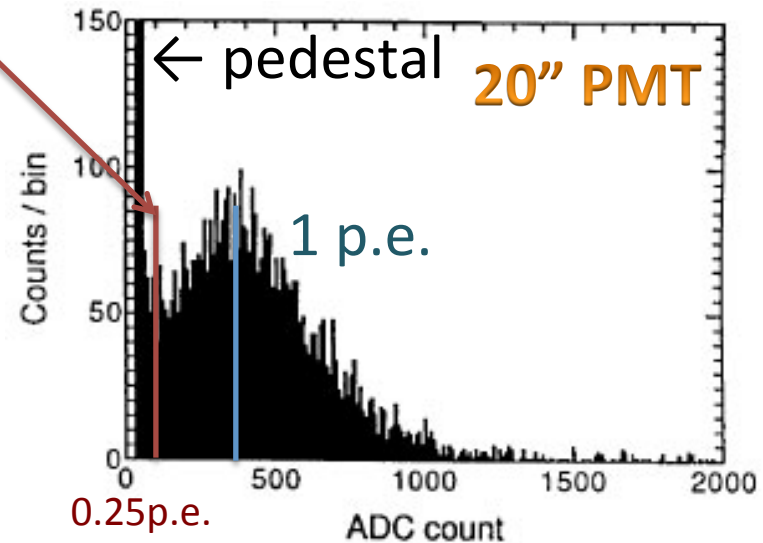
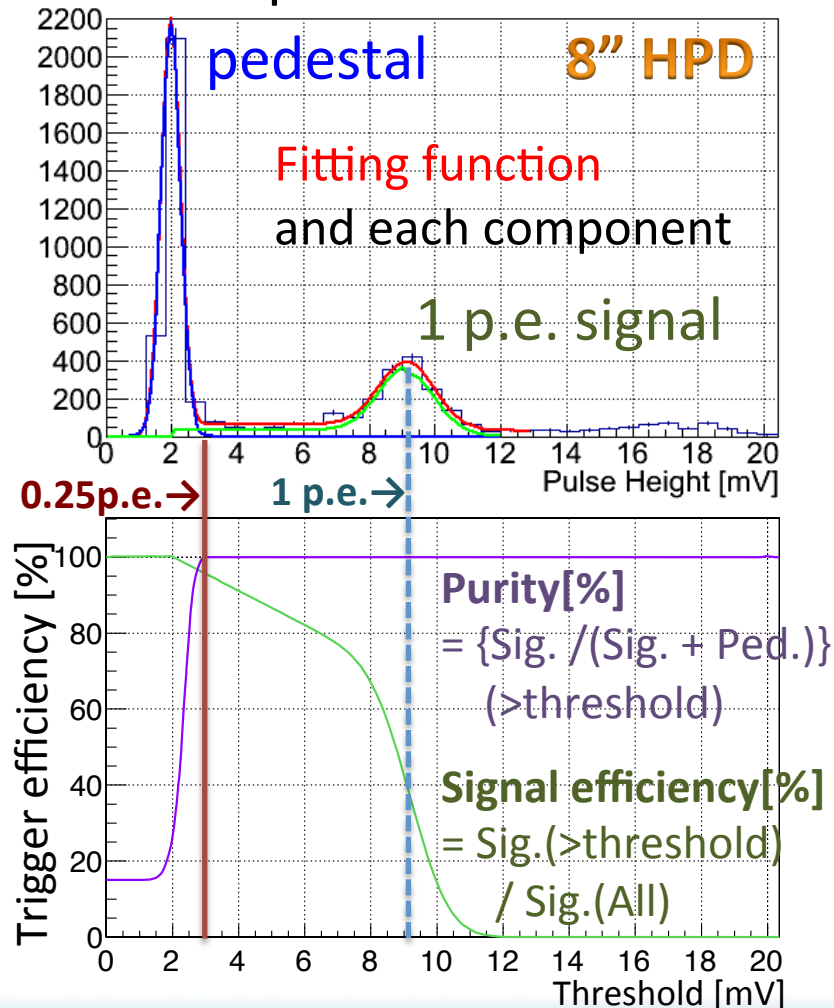


- Gain is adjusted by AD bias HV.
- 10 HPDs are selected by dark rate less than 35 kHz.
- 4.5kHz at typical 20" PMT
- Dark rate is expected to be stabilized after a long operation (a few months ~ a year)

Hit threshold and efficiency

0.25 p.e. threshold is set for 1 hit at Super-K (20" PMT)

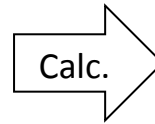
1 photon events



- Better trigger efficiency is expected thanks to narrow 1 p.e. peak at 8" HPD.
- Even if threshold is higher than 0.25 p.e.
- Calibration setup and gain, threshold optimization in Feb 2013.

20-inch HPD development

- 20-inch HPD R&D started.
 - E-field calculation and design finished.



(20-inch)	C.E.	Q.E.	TTS _(FWHM)
Super-K PMT	80%	22%	5.5ns
High-QE HPD	95%	30%	1.1ns

Detection efficiency is **60%** UP in total.

Solved many difficulties

- E-field, e-track calculation
- Bearing pressure, stress analysis
- Ground pin penetrating glass

● Specification

- Bias HV : 8kV (Same as 8" HPD)
- AD $\Phi 20\text{mm}$ ($\Phi 5\text{mm}$ in 8" HPD)
- and implementation based on 8" HPD test

● Make prototype step by step (Since Spring 2013)

Fix spec. within 2013

(Prototypes •

Design end cap

/explosion-proof case •

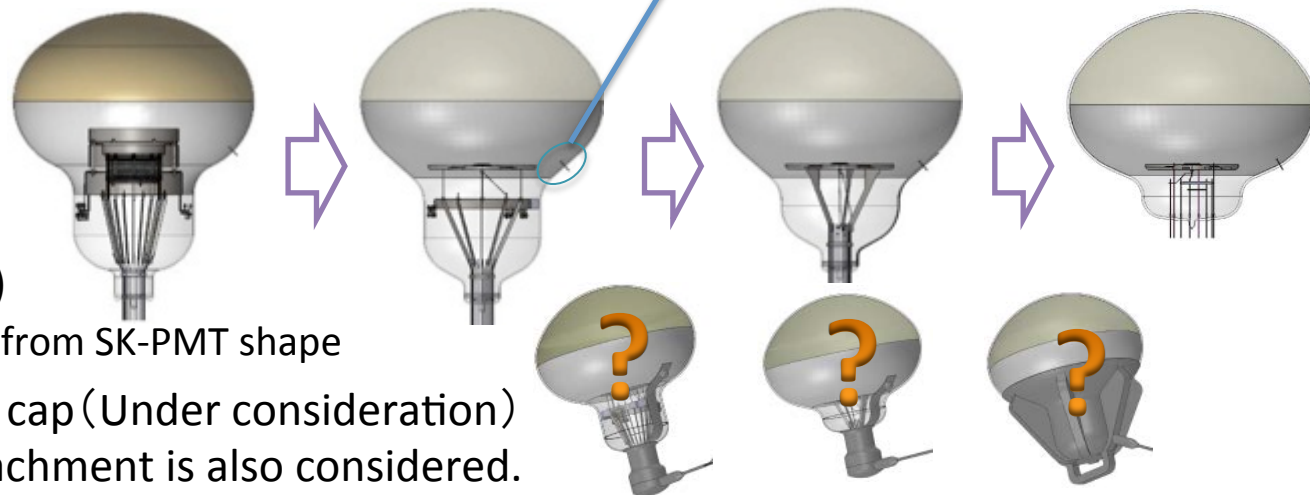
Performance measurement)

Start from SK-PMT shape

Water-proof end cap (Under consideration)

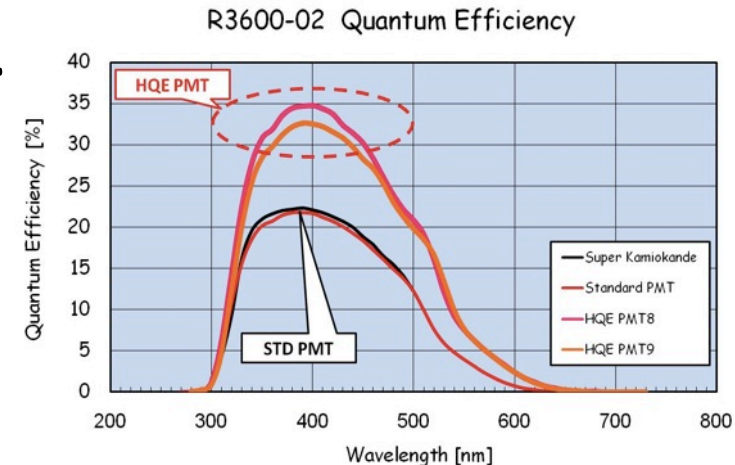
A combined case / tank-attachment is also considered.

- Prototype measurement in 2013-2014, ready for proof test in 2014.



High Quantum Efficiency

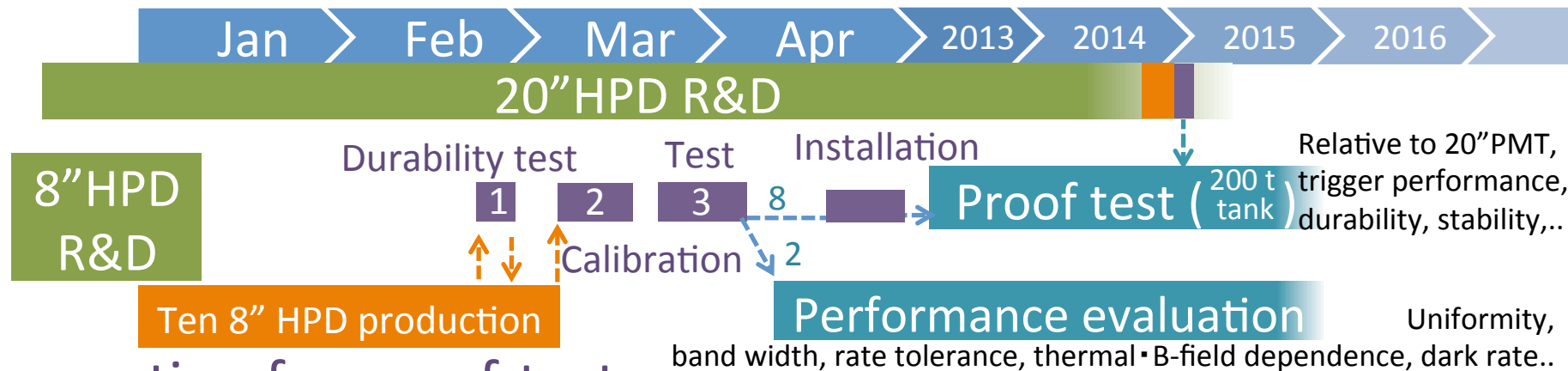
- High Q.E. study starts from PMT, then HPD (after its R&D).
 - High Q.E. is the common upgrade option for both PMT and HPD.
 - ▶ Study especially for trigger is required, because photocathode (related to dark rate) is changed.
- **20" high-QE PMT** is provided soon.
 - Completely same design and material as SK PMT, except for photocathode.
 - **30% QE** (22% in SK PMT)
 - 8 high-QE PMTs arrive at Kamioka.
(2 in February, and 6 in March 2013)
 - Plan to install 5 high-QE PMTs in EGADS 200-ton tank at 1st installation of SK-PMT and HPD.



Hamamatsu Photonics has already produced several PMTs.

Proof test of 20" High-QE PMT starts concurrently with (normal-QE) 8" HPD.

Schedule



Preparation for proof-test

1. Pre-test to check durability (18/Feb – 1/Mar)

- 10 HPDs arrive on 18 Feb w/o water proofing.
- 3-day running test, HV switching 100 times, and simple checks.

2. Calibration and safety test (11-22/Mar)

- Gain adjustment for water-proof 10 HPDs.
- Selection (P/V ratio > 1.3 and dark rate < 35 kHz)
- Gd water test for all 10 HPDs.

3. Stability test for 2 weeks

- Final check of stability in a long operation.

● HPDs are ready for the proof test from Apr 2013.

- 8 HPDs for the proof test, 2 HPDs for more detailed evaluation.

Summary

- 8-inch HPD is now prepared for proof test in 200t tank.
 - HPD and pre-amplifier were tuned.
 - ▶ Fix discharge, reduce noise, optimize amplifier, ..
 - Long time running, durability of HV switching and safety operation in water were checked.
- Production of ten 8" HPDs has started.
 - Some small checks for each new HPD will be made in February.
 - Then HPDs will be water-proofed, and calibrations made in March.
- Proof test will start in next spring 2013.

Dark rate for a year

- 20" PMT dark rate in 1st year of Super-K

