Status and Prospect of the Photo-detector Development in Kamioka

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5th Hyper-K open Meting

21/Jul/2014

Contents

Outline and prospect of photosensor R&D in Japan

- Other related study of performance
  - Pulse shape
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- R&D status and options
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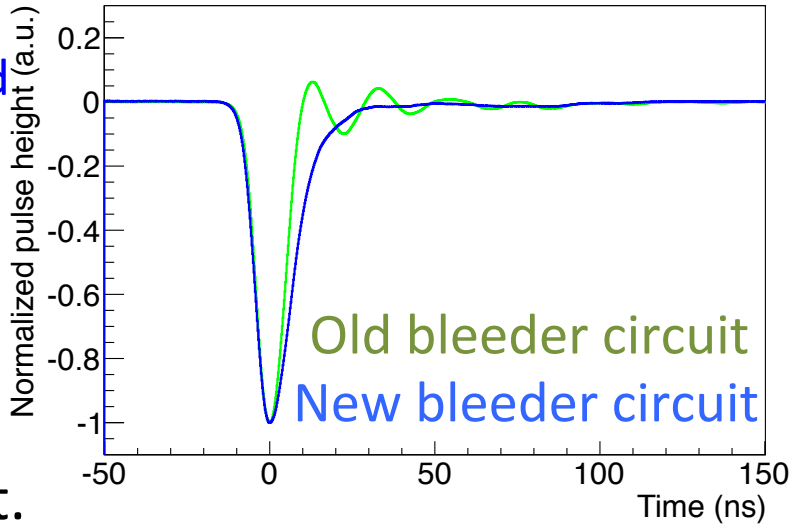
- Overview of test and performance

Optimization of pulse shape

Pulse shape of HPD/PMT was optimized in electronics.

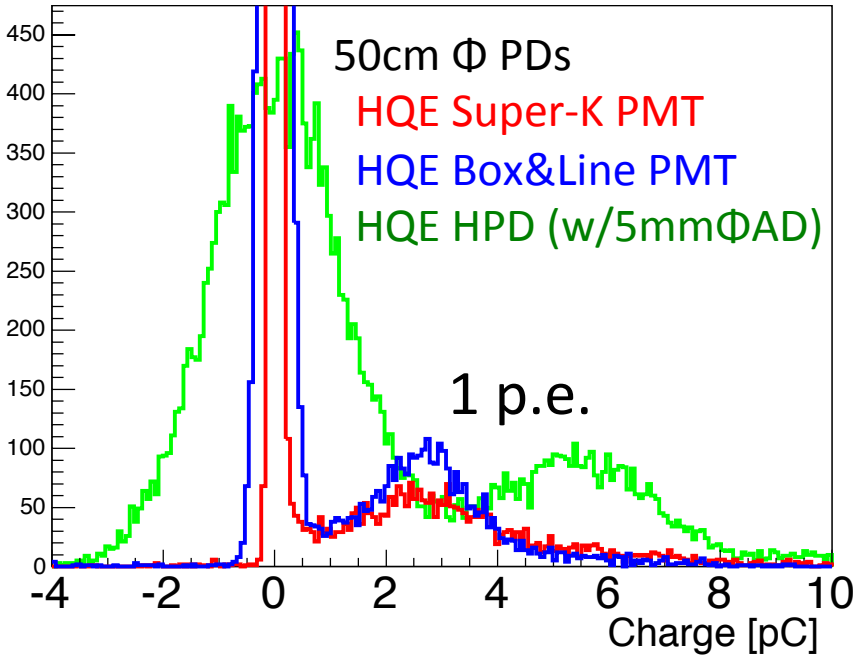
- 8” HPD preamplifier (Jan 2013)
  - CR time constant in preamplifier was adjusted to get enough charge resolution for EGADS proof test.
- 20” Box&Line PMT bleeder circuit (May-Jun 2014)
  - Two types of bleeder circuit were tested. (damping resistor, etc.)
    1. Fast response with residual ringing
    2. Smooth recovery with ringing suppressed
       - New with adjusting damping resistor
  - Pulse FWHM 10.4ns ↔ 12.9ns
  - Pulse height 1.3 : 1
  - Performance and charge gain are almost similar.
  - Adopt 2. bleeder circuit for proof test.



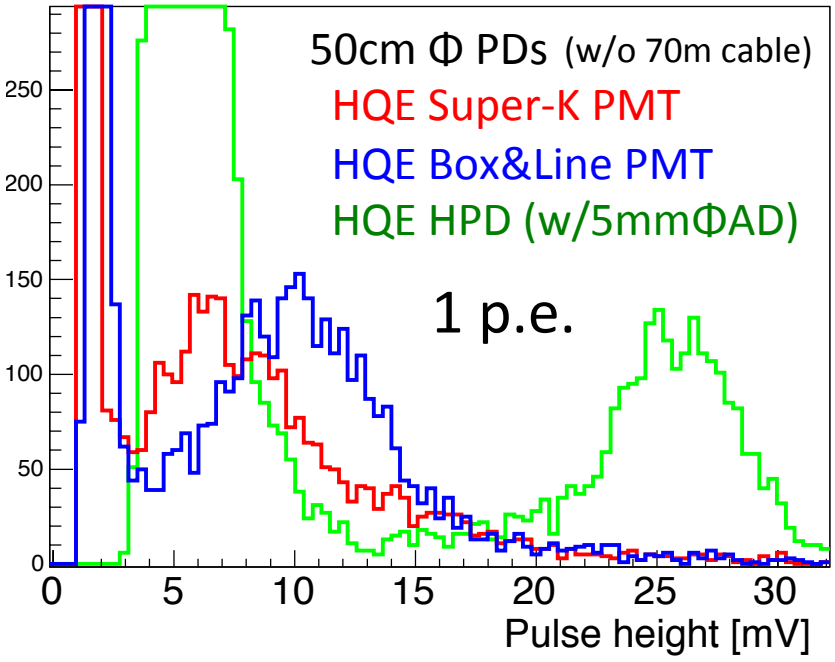
Pulse height distribution

- Minimum hit threshold is restricted by noise level.
  - SK PMT threshold is set at 0.25 p.e. (1 mV) in proof test (w/ 70m cable)
  - 8” HPD threshold is set at 0.5 p.e. (4 mV) in proof test

1 p.e. charge distribution



1 p.e. pulse height distribution



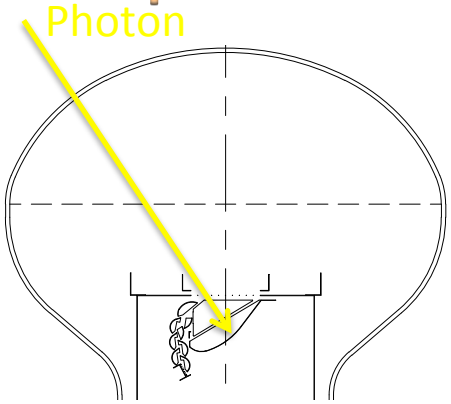
PMTs : Gain set at same 10^7 ⟶ Peak at pulse height differs by its time response
HPD : Larger electronic noise ⟶ Good 1 p.e. separation in pulse height

Better single hit efficiency is expected in new photodetectors.

After pulse in PMT

Usual pulse might be accompanied with other pulses.

Pre pulse

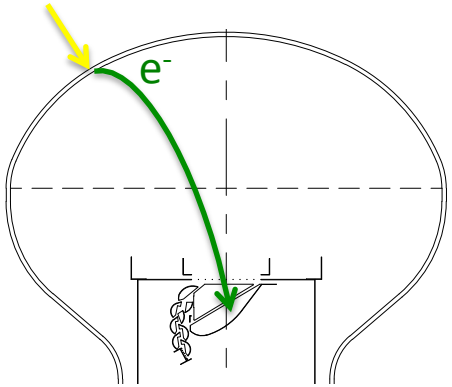


A few tens nsec faster than main pulse. It depends on dynode structure and injection angle. Few rate and less gain are expected.

0 nsec

(-100 nsec –)

Main pulse



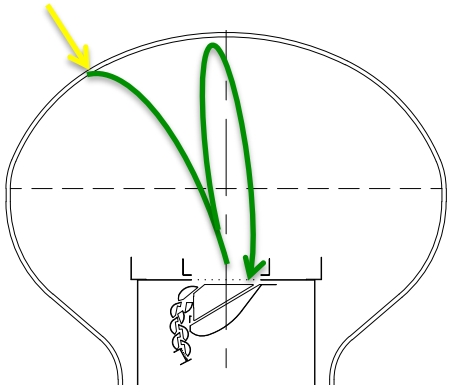
Main signal. Transit time (TT) from photocathode to 1st dynode depends on a bias voltage a little.

0 nsec + TT

(Transit Time)

(Within T resolution & time walk)

Late pulse

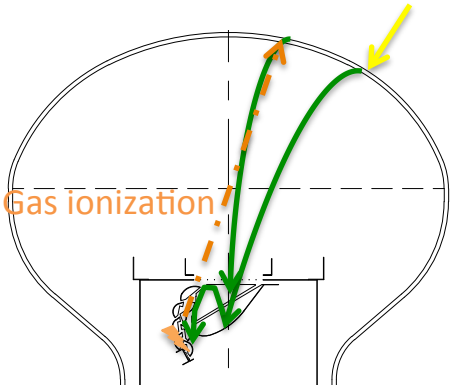


Photoelectron gets back scattered on 1st dynode w/o multiplication. It takes three times more than transit time.

0 nsec + 3 x TT

(30 - 150 nsec)

After pulse



Residual gas in vacuum is ionized and goes back to photocathode, then photoelectron is emitted again. Time depends on its ion mass.

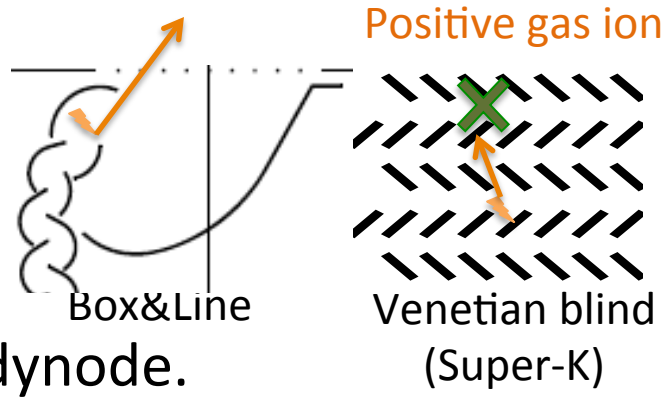
0 nsec + TT of e^- and gas ion

(150 nsec – 100 μsec)

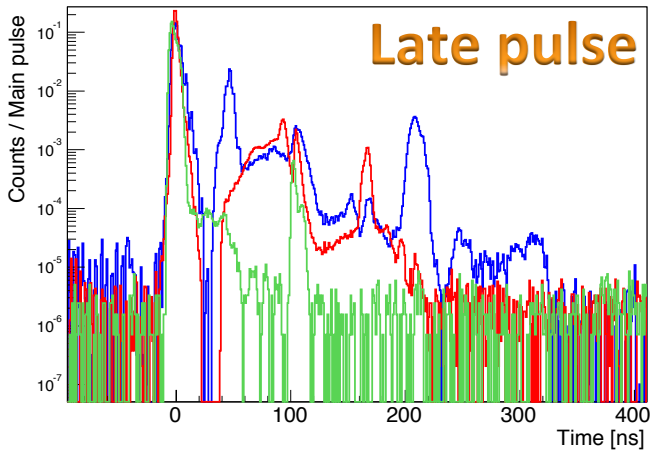
- Ringing, reflection in bleeder circuit might also appear.

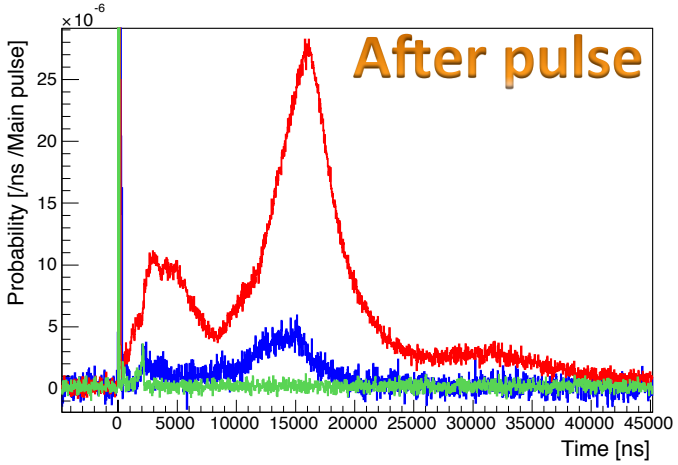
After pulse with in new PDs

- Much pulse by Box&Line dynode
  - Dynodes of Box&Line PMT opened to photocathode largely, which can allow gas ionization to move back on photocathode easier than Venetian blind dynode.



- Less pulse in HPD expected
  - No metal dynodes could avoid ionization gas during multiplication.
  - Avalanche diode has after pulse also, but it is much less than MPPC (SiPM) operated in Geiger mode. (To be studied)





50cm Φ PDs
HQE Super-K PMT
HQE Box&Line PMT
HQE HPD (w/5mmΦAD)

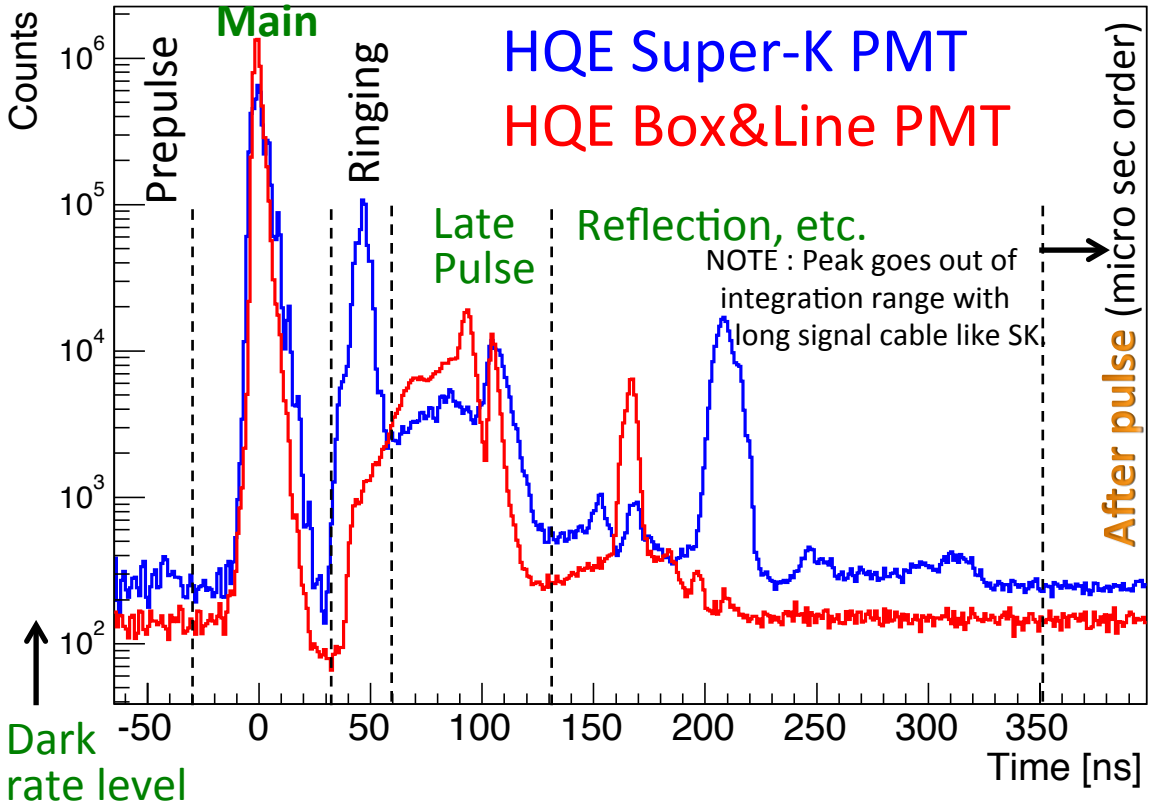
NOTE : HPD w/5mm Φ AD prototype has less collection efficiency, half than its design (20mmΦ). Need evaluation in final design.

PMT late pulse measurement

Pulse measured at 0.25 p.e. level around 1 p.e signal using multi hit TDC with 20 nsec counting

Pulses within 400 ns integration range

(All integrated as 1 hit in Super-K)

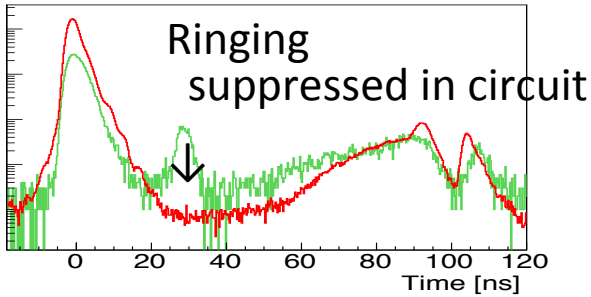


Evaluation of relative pulse rate :

1. Dark rate using off-time events before main pulse.
2. Count in each time window.
3. Relative ratio to main pulse.

- Ringing depends on circuit

  Less ringing in HQE Box&Line PMT (Fast-response bleeder circuit w/ ringing at 0.5 p.e. thre.)



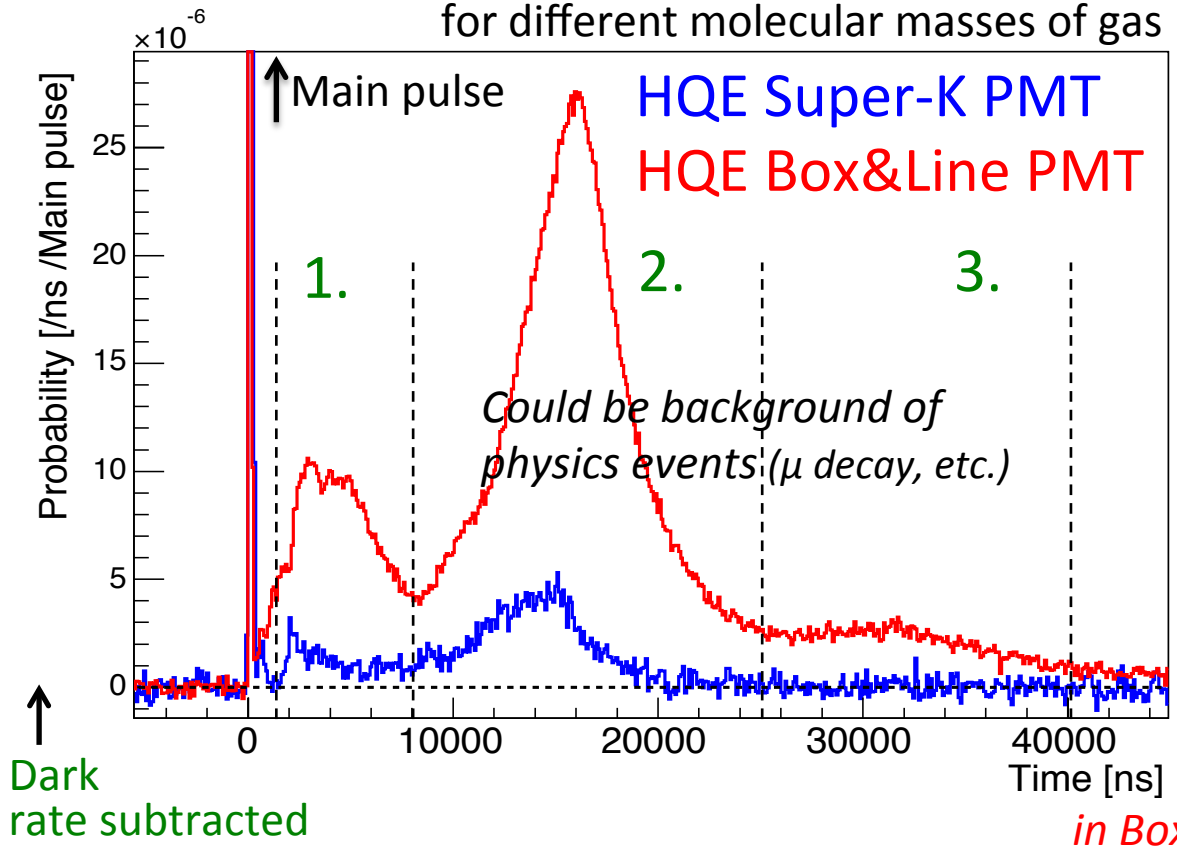
  - No problem in integration, accompanied with main pulse.
- Reflection time varied by cable length.
  - In SK, out of range for integration.

Comparable pulse rates in both cases

PMT after pulse measurement

Pulse measured at 0.25 p.e. level around 1 p.e signal using multi hit TDC with 20 nsec counting

After Pulses Define in 3 regions for different molecular masses of gas



Evaluation of relative pulse rate :

1. Dark rate using off-time events before main pulse.
2. Count in each time window.
3. Relative ratio to main pulse.

Peak timing determined by

- Molecular mass of gas
- Bias voltage
- Drift length

Contamination changed by residual gas, thus

- Time after HV applied
- Aging after a long run
- Gas leak from outside
- Individual quality in production, …

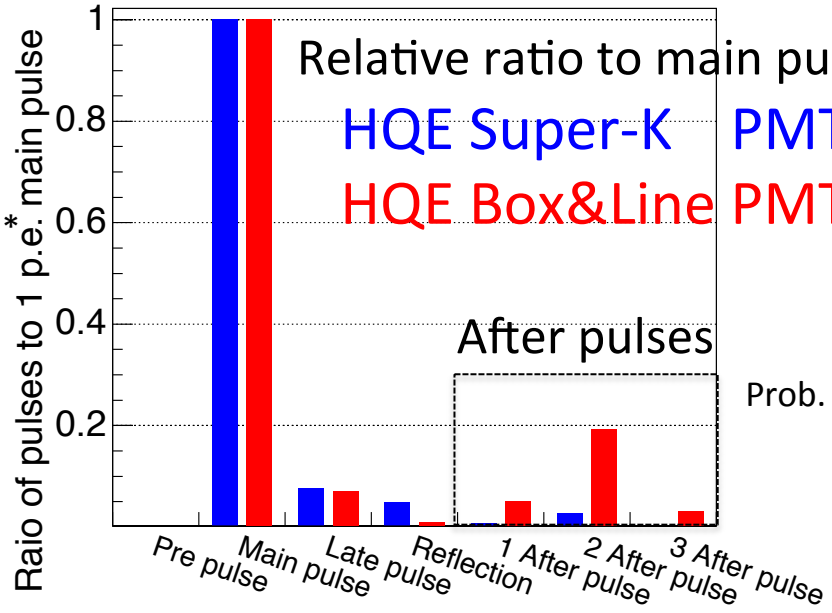
Observed much pulse rate in Box&Line PMT as expected from design.

After pulse rate

Preliminary

Each measurement in one PMT sample

*Contamination of 2 or more p.e. still exists.



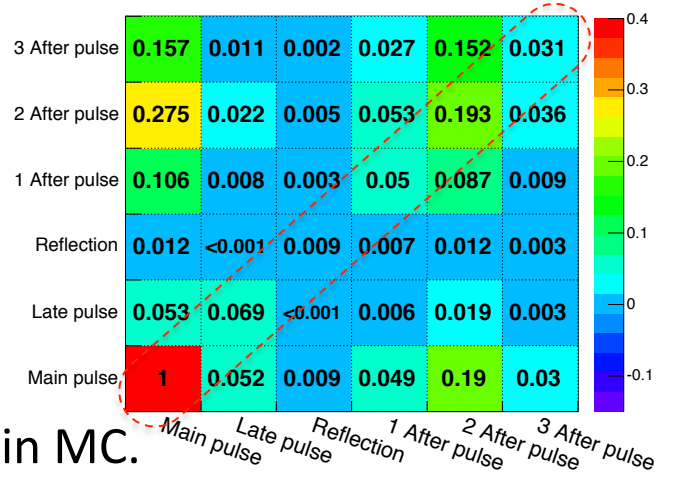
Relative (diagonal) and coincidence prob. P(X|Y)

HQE Super-K PMT

Prob. if main pulse exists →

Negative values from dark rate subtraction in few statistics.

HQE Box&Line PMT



- Box&Line PMT shows after pulses
  10 times more than SK PMT's.
- Study is still continued.
  - On several samples for both only single p.e. case, and high intensity case to find low gain pulse.
  - Utilize rate for quality control and BKG estimation in MC.

To Do on after pulse

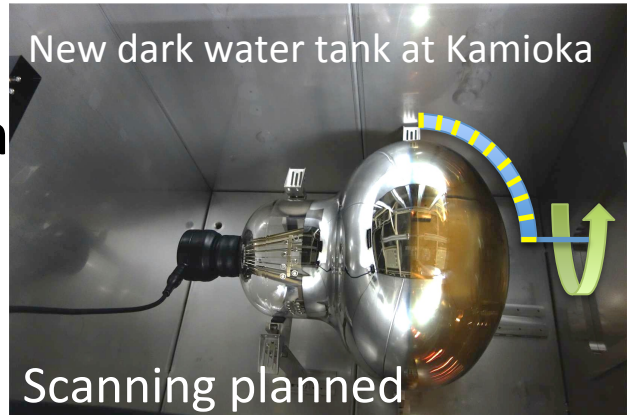
- Transition of after pulse rate in long run
  will be measured for a year.
- Pulses with small gain is also identified
  with high intensity measurement.

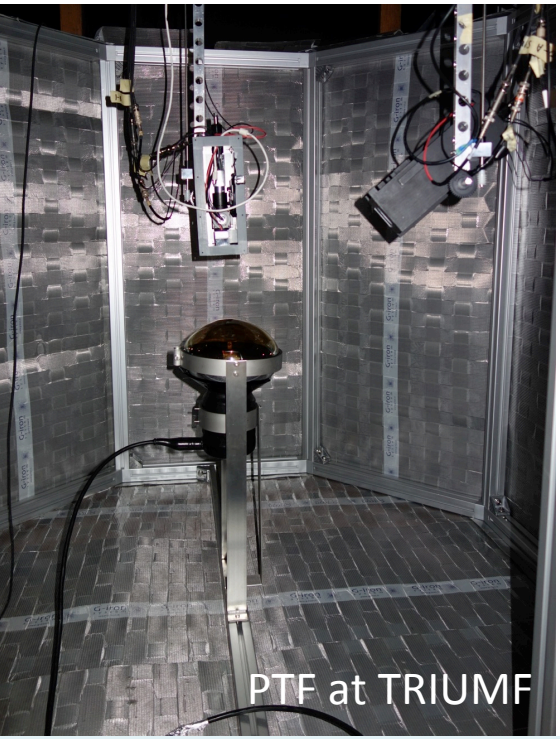
- After pulse can be backgrounds to find decayed electron from muon in 2.2 us mean lifetime, coincidence physics event, etc.
  - In Super-K, after pulse is considered in analysis.
  - Need evaluation how much after pulse rate affects decayed electron tagging in MC.
  - Measured profile of timing, charge and frequency
    is required in each photodetector.

Response and uniformity

Measure box&line PMT property at Kamioka in a few months.

- CE and QE uniformity
- Time offset and resolution, charge resolution
- Response by various magnetic field
- These response by different HV

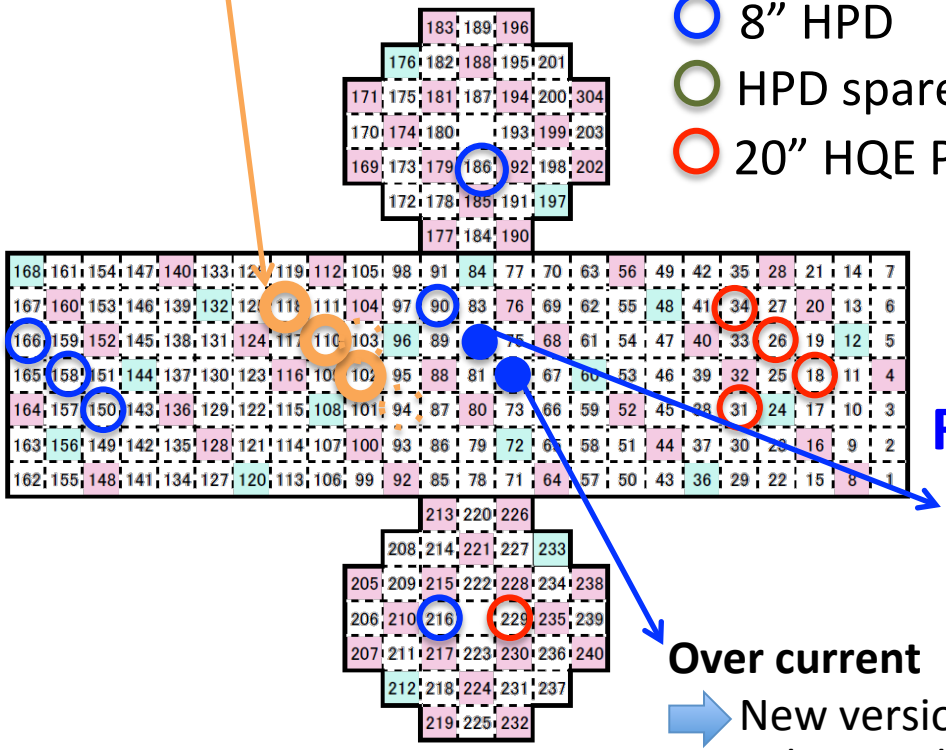




- HPD setup in Photosensor Test Facility (TRIUMF)
  - 8” HPD was arrived at TRIUMF.
    - Mounting and signal check were done.
    - Can measure optical property and response in water
  - Details in “Status of the Photosensor Testing Facility” in calibration session by Tom.

Next stage of proof test

Install three of 20” high-QE Box&Line PMTs



Replace two 8” HPDs

High rate

Investigate source of high rate, etc.

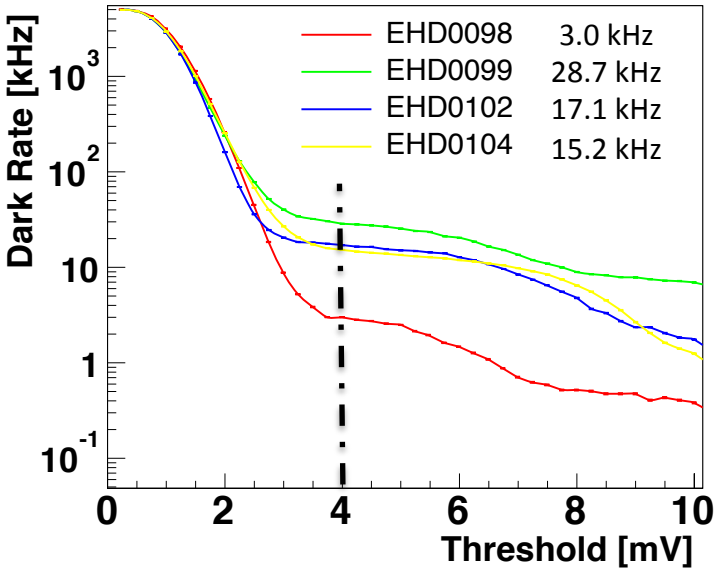
Over current

New version of HV module designed with high withstand voltage, low noise, wide HV range for future.

- Installation in August 2014
- Restart from September 2014

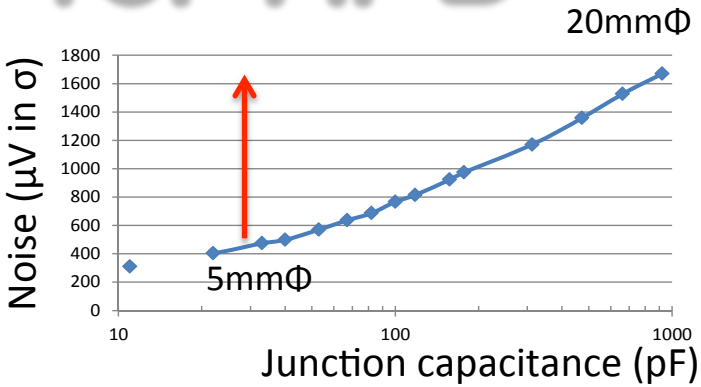
Pre-calibration for proof test

- Measured 4 HPDs to select two candidates for installation.
  - Pre-selection on performance done
    - Peak to valley ratio between pedestal and 1 p.e. is sufficiently better than 1.2
    - Dark rate less than 35 kHz
  - Tested for continuous 3 days
  - Durability test with 100 times HV power cycle

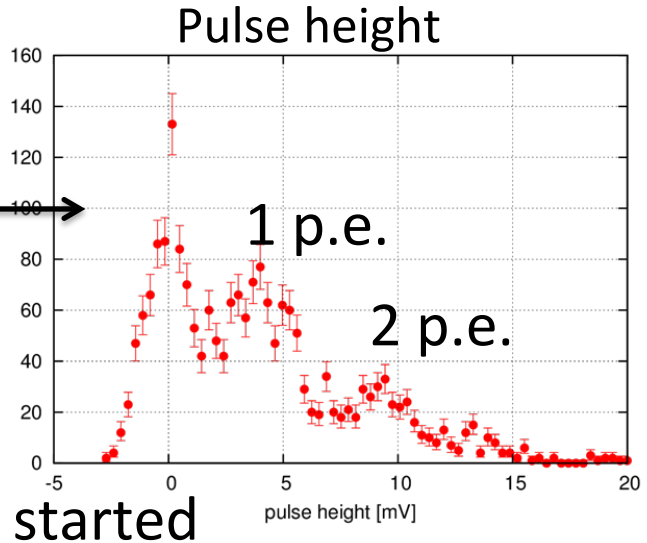


- Thee box&line PMTs waterproofed for proof test will be delivered soon to Kamioka.
  - Calibration and pre selection for a week
  - Compatible design with SK PMT
- Next update on 20" HPD in autumn 2014, and proof test in 2015.
  - New AD, amplifier, ..

Preamplifier R&D for HPD



- Large junction capacitance is critical to read signal from 20mm Φ AD.
- R&D ongoing in several options
  - Half junction capacity with another AD manufacture process
  - Pixelized AD up to 5 segmentation and sum amp
  - Electric field redesigning with smaller focus area
  - Preamplifier development
- Initial preamplifier test with existing charge amp, and new <u>boot strap amp</u> were tried on 20mm Φ AD read out.
  - Single p.e. signal is barely confirmed.
  - Still problem about hit trigger, time response, white noise… and R&D just started



High voltage power for HPD

- Built-in HV power supply are being developed by four manufacturers.
  - One is used in current HPD, two are ready soon and other under design.
  - Plan of durability test to estimate life time, and performance evaluation with implementation during R&D process from autumn 2014.
  - Digital control line, instead of many analog lines, is under consideration.
    - Currently +10/GND power, HV/LV control, enable, over current, … in analog
  - Radiator design into water is important to avoid heating around AD.
  - Select cheap and reliable module with sufficient performance by test.

- Multi-(or single) channel HV power supply in waterproof front-end module is also another option considering redundancy.
  - New technology should be established due to difficulty of high 10 kV line.
  - Thin and tough long HV cable for 10 kV with few current, 2ch lines in each HPD
  - HV connector in high pressure water

- Test is required in high pressure water, and in HK prototype detector.

Approach to achieve few failure rate

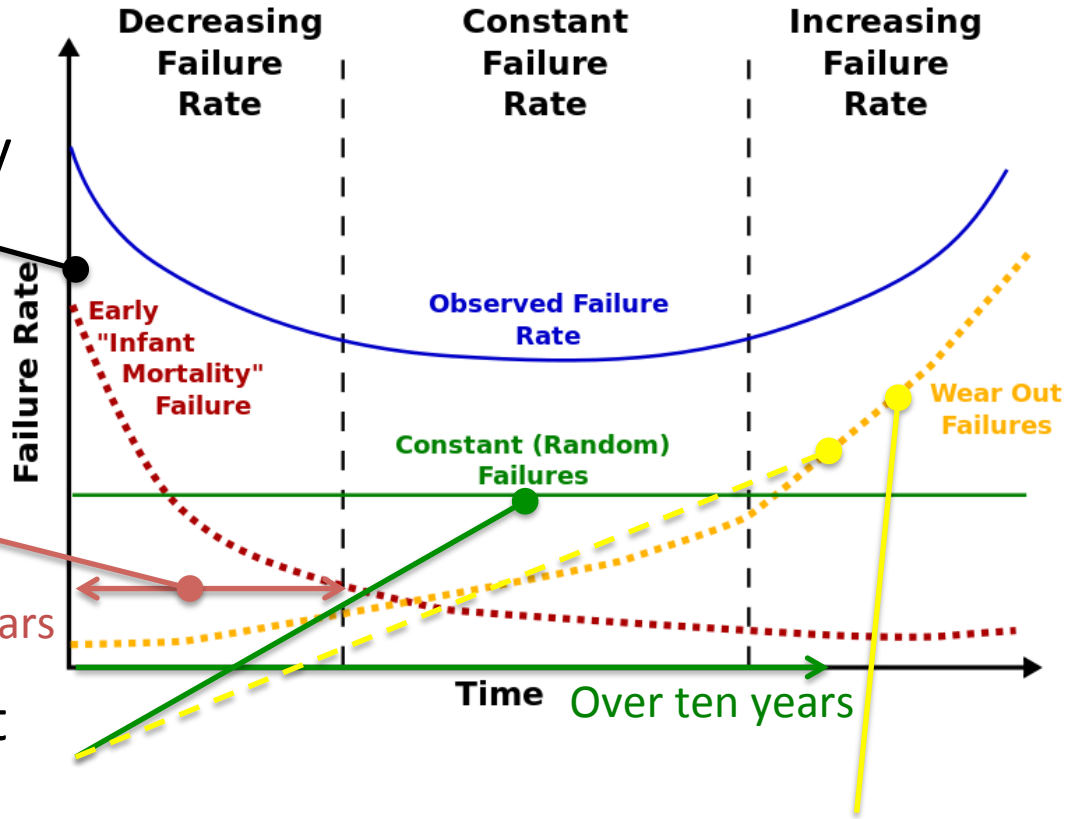
What can we do in R&D?

- Initial failure is found by quality verification in factory or check and pre-test at Kamioka
- Early failure and performance are evaluated in EGADS proof test for a few years run

A few months ~ years

- Accelerated degradation test for 15-30 years in Hyper-K
  - Power cycle test (HV, amp, etc.)
    - Tested in HPD (30,000 cycles) before proof test
  - Aging test (accumulated light, current, etc.)
    - Not yet done, but planned

Wikipedia : Bathtub curve



- Design life, rating life
  - Selection of reliable parts, test
  - Reliability and experience
  - Maintenance option in HK

Performance overview

	8" HPD	High QE	20" HPD	20" Box&Line	SK PMT
Intrinsic resolution	◎	-	◎	◎	○
Measured resolution	◎	-	◎	◎	○
Dark rate	◎	△	?	?	○
Collection Efficiency	98%	-	95%	93%	80%
B-filed tolerance	◎	-	◎	○	○
After pulse	◎	-	◎	△	○
Noise from electronics	△	-	△	○	○
Gain thermal dependence	△	-	△	○	○
Power consumption (Valve)	◎	-	◎	○	○
Power consumption (HV/amp)	○	-	○	◎	◎
Test status	In tank	In tank	(2015)	Soon	In tank
R&D progress	Update is planned	○	Ongoing (AD, amp)	Ready for test	◎
Reliability	?	?	?	○?	◎

Summary

- Effect of after pulse from new photodetectors should be studied in MC simulation with measured profile.
- Preamplifier for 20” HPD is essential and difficult. Several options of AD readout are considered.
- Next validity test will start soon with 20” box&line PMTs. Durability test outside tank is also planned.

- There are still many study items. All evaluations will end by 2016 to select the best photodetector for Hyper-K.