Detailed performance evaluation of New 50 cm Photodetectors for Hyper-Kamiokande

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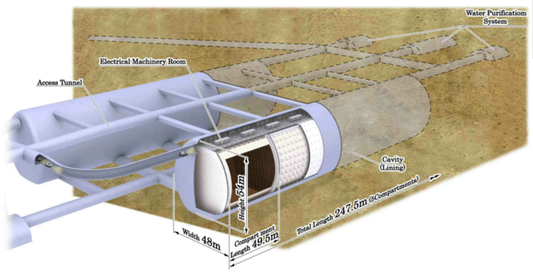
Hyper-Kamiokande project

Next generation water Cherenkov detector
- Volume : 0.99Mt (Super-K × 25 in fiducial volume)
- Inner detector photo sensors : 99,000(Super-K:11,129)
- Outer detector photo sensors : 25,000(Super-K:1,885)
- Photo coverage : 20%(Super-K:40%)



Search for CP violation, mass hierarchy, nucleon decay, super-nova relic neutrinos.

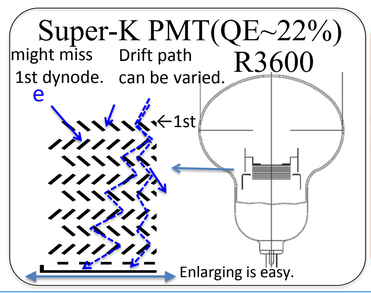
Reference – arXiv :1109.3262v1: Letter of Intent : The Hyper-Kamiokande Experiment Detector Design and Physics Potential

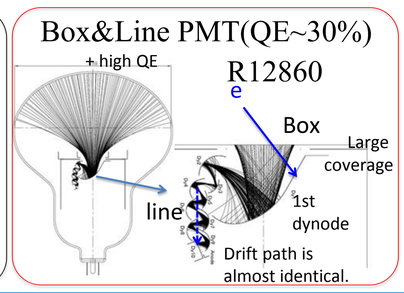
Required performance of photo sensors (Box&Line PMT).
- Better timing resolution
- Better photoelectron resolution
- High rate tolerance
- Quick gain recovery
- Low noise
- High magnetic field tolerance

etc…

50cm Box & Line PMT (Hamamatsu R12860)

➢ One candidate of photo-sensor is **50cm Box&Line PMT**





43cm (17-inch) Box&Line PMT is currently used for KamLand experiment.
➢ The new Box&Line PMT for Hyper-Kamiokande was developed to reach 50cm φ detection area and high quantum efficiency.

Performance

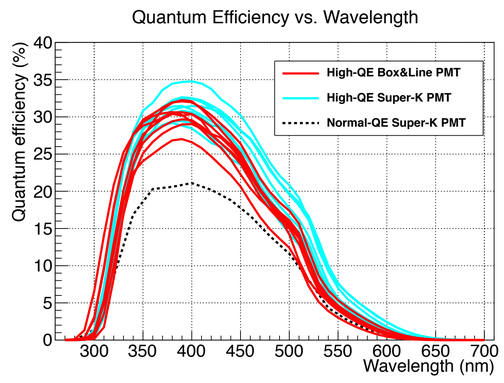
Efficiency

Box&Line PMT has high collection efficiency and quantum efficiency.

	R3600(Super-K PMT) (Normal photocathode)	Box&Line PMT (High QE photocathode)
Quantum efficiency	~22%	~30%
Collection efficiency	67% (61%)	95% (85%)
Sensor Efficiency (QE × CE)	~15%(~13%)	~29% (~26%)

: φ 460 mm (φ 498 mm)

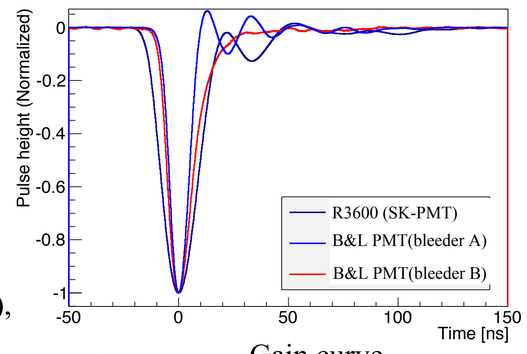
Reference – NNN14: talk by Nakayama : HyperKamiokande R&D



Pulse shape

Box&Line PMT has faster pulse shape than R3600

	Rise time (10%-90%)	Fall time (10%-90%)	Pulse width (FWHM)
R3600	10.6 ns	13.2 ns	18.8 ns
20" High QE Box & Line PMT (Bleeder A)	6.2 ns	6.3 ns	10.0 ns
20" High QE Box & Line PMT (Bleeder B)	6.8 ns	15.2ns	13.2 ns



Due to the development of new bleeder circuit (Bleeder B), the ringing effect of new Box&Line PMT becomes small.

Reference – NNN14: talk by Nakayama : HyperKamiokande R&D

Gain

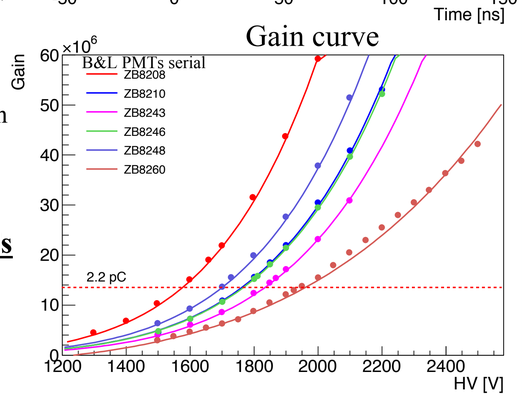
$\delta = a \times E^N$

δ : Amplification rate of photoelectron
a : Constant
N : Constant
E : High voltage

Six Box&Line PMTs were measured. **All Box&Line PMTs are consistent with a numerical formula, $\delta = a \times E^N$.**

Based on the R3600 setting at Super-Kamiokande, HV of each PMT is set to the value whose 1 p.e. gain is 2.2 pC.

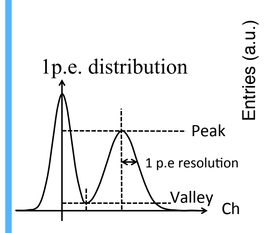
Reference – NNN14: talk by Nakayama : HyperKamiokande R&D

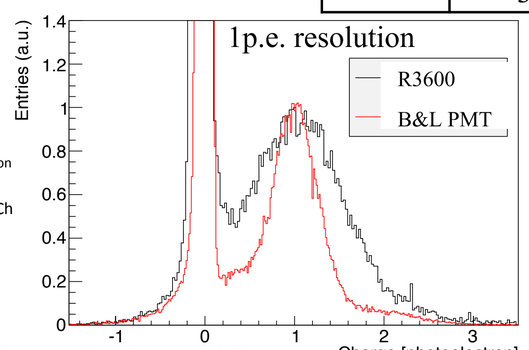


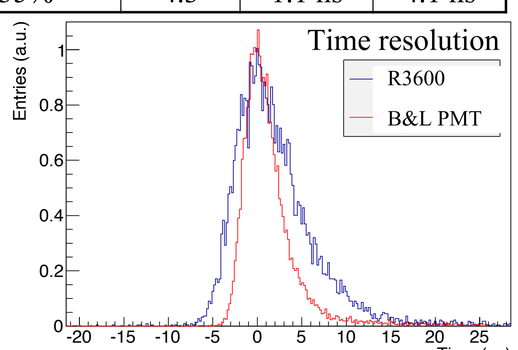
1p.e. resolution

Box&Line PMT is improved in photoelectron and time resolution compered to R3600 .

	1p.e. resolution σ/peak	Peak/ Valley	Timing Resolution σ	Timing Resolution FWHM
R3600	53%	2.2	2.1 ns	7.3 ns
B&L PMT	35%	4.3	1.1 ns	4.1 ns







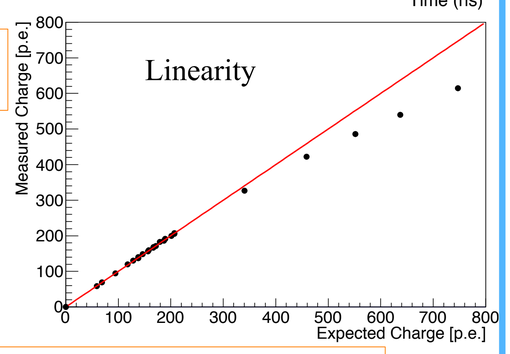
Reference – NNN14: talk by Nakayama : HyperKamiokande R&D

Linearity

Requirement for Hyper-K : Stable gain from 1 p.e. level to several hundreds p.e. level.

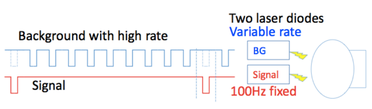
The linearity is kept up to 340 p.e. within gain drop less than 5%.

The signal of large number of photoelectron (> 340 p.e.) will be collected by the measurement.

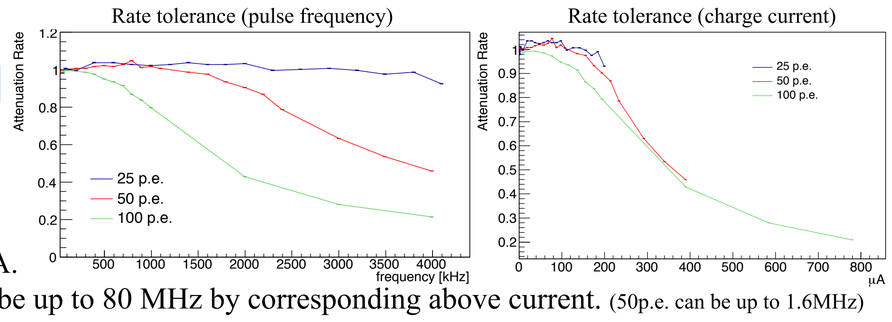


Rate tolerance

Rate tolerance is necessary for Supernova measurement and so on.
➢ Supernova of Betelgeuse will bring 10 MHz neutrino interaction at maximum (1p.e. level).



Two laser diodes were used
➢ Different background configuration.

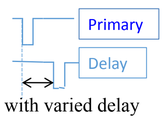


Gain kept stable, up to 170 μA.
For 1 p.e. signal, the rate can be up to 80 MHz by corresponding above current. (50p.e. can be up to 1.6MHz)
➢ **Enough tolerance to measure supernova with constant gain.**

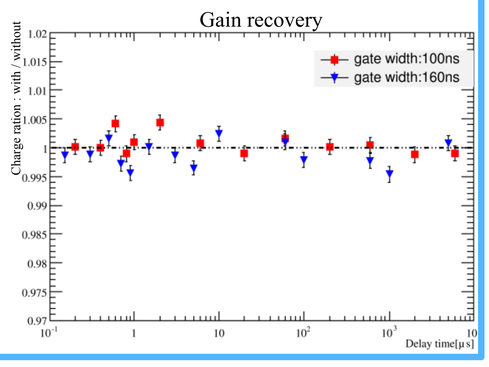
Gain recovery

A quick gain recovery is important to identify a delayed event in Hyper-K, such as decay electron from μ.

Two LDs (140p.e. for each)



The performance is evaluated by comparing "delayed signal with primary" and "delayed signal without primary".



No significant changes were observed, and the gain is stable within 0.5% (only statistical fluctuation).

Noise reduction

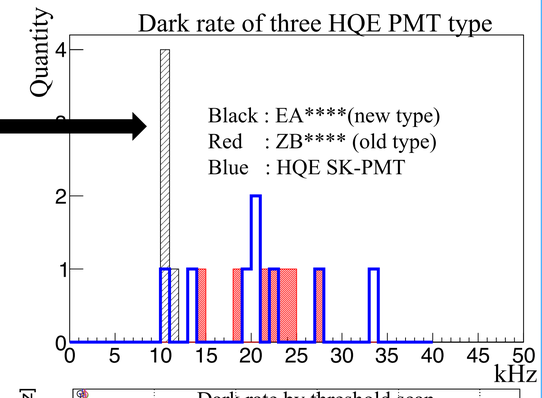
High dark rate (> 20kHz) and large after pulse is shown in the old type Box&Line PMT(ZB****).
➢ **Low noise type Box&Line PMT(EA****) was developed.**

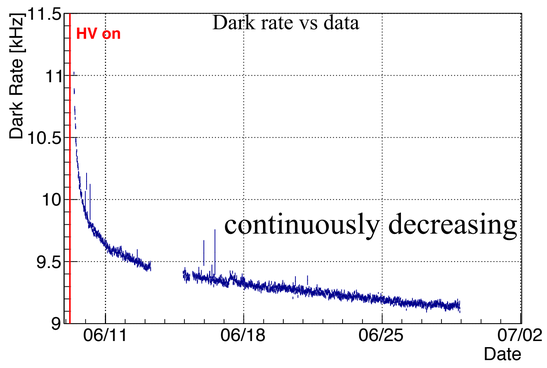
Dark rate

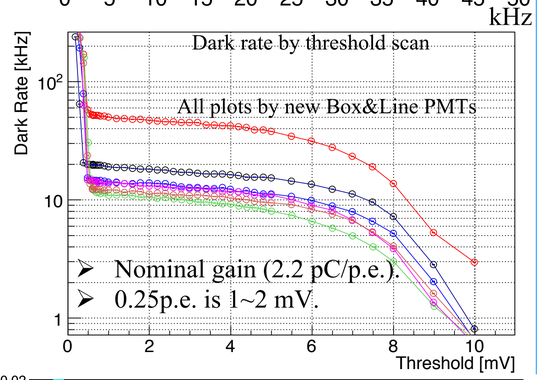
Dark noise affects an accuracy of event reconstruction.

Dark rate was reduced about 10 kHz
- ➢ By improvement of photocathode.
- ➢ Comparable level as R3600 considering high QE and CE.

The dark rate was checked before stabilization at room temperature, therefore it is expected to be lowered in Hyper-K environment (after stabilized in lower temperature).





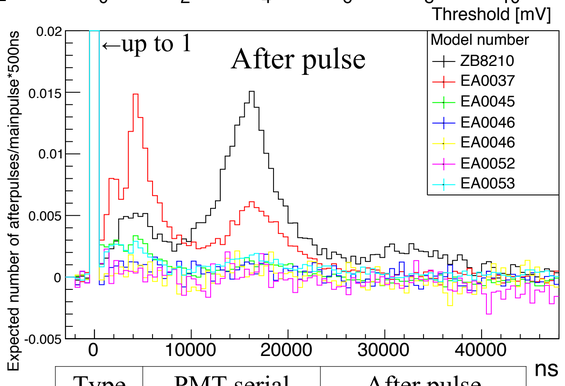


After pulse

An "After pulse" is occasionally accompanies by a primary pulse signal.

An after pulse is coincident signals with decay electrons via muon decay.

- A large rate of after pulses, about 30% compared with a primary pulse, was shown in the previous Box&Line PMT (ZB8210).
  - ➢ Recent improvement by Hamamatsu gave reduction of the after pulse.
- **New PMTs showed largely reduced after pulse rate comparable with Super-K PMT.**
- EA0037 got still high rate, but it is probably due to the initial production stage.



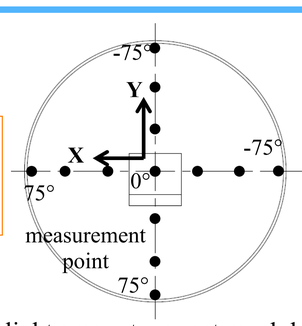
Type	PMT serial	After pulse
Old	ZB8210	0.32±0.03
New	EA0037	0.23±0.04
New	EA0045	0.04±0.02
New	EA0046	0.02±0.01
New	EA0047	0±0.02
New	EA0052	-0.02±0.02
New	EA0053	0.07±0.04

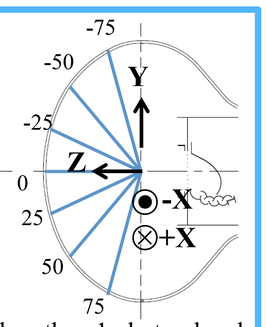
Magnetic field tolerance

Position dependence

In Hyper-K, coils will be arrange around the tank to reduce geomagnetic field. The residual magnetic field for the Hyper-K at most a 100 mG level.

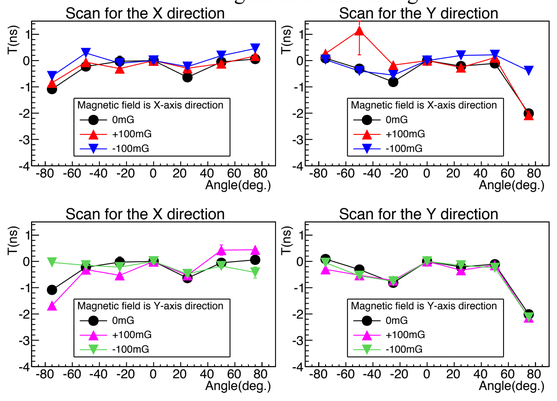
- ➢ Measurement was performed along the dynode symmetry direction (X-axis) and asymmetry direction (Y-axis).
- ➢ Measurement points were at 0, 25, 50, 75 degree.
- ➢ Threshold was 0.25p.e. of 0 mG and 0 degree.



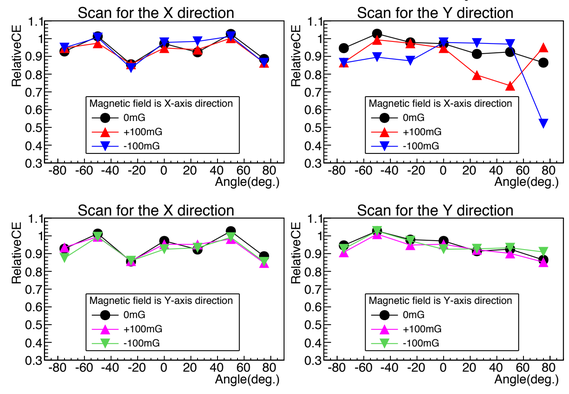


- ➢ The light amount was set much less than 1 photon level
- ➢ HV was set to 2000V.

Difference of signal detection timing



Difference of relative Collection Efficiency



- ➢ **Maximum timing difference was less than 0.7ns, that is similar to the design value. It was also small compared to the timing resolution value (FWHM 4.1 ns).**
- ➢ **The difference of the collection efficiency was similar to the design value. The effect can be ignored**, however, the aforementioned deficit appears only along one direction in this case; thus, it is possible to be reduced by considering the mounting direction at Hyper-K.

Summary

- We have developed the Box&Line PMT for Hyper-K.
- The requested performances test of Box&Line PMT for Hyper-K were pereformed.
- As a result, it was shown that Box&Line PMT has better performance than current Super-K PMT and confirmed to be sufficient for Hyper-K.

➢ 50cm Box&Line PMT (R12860) is ready for use in the Hyper-K.
(as for the detection performance)