Improvement of Energy Resolution in KamLAND-Zen by Implementing Signal Amplifier for Low-gain PMTs

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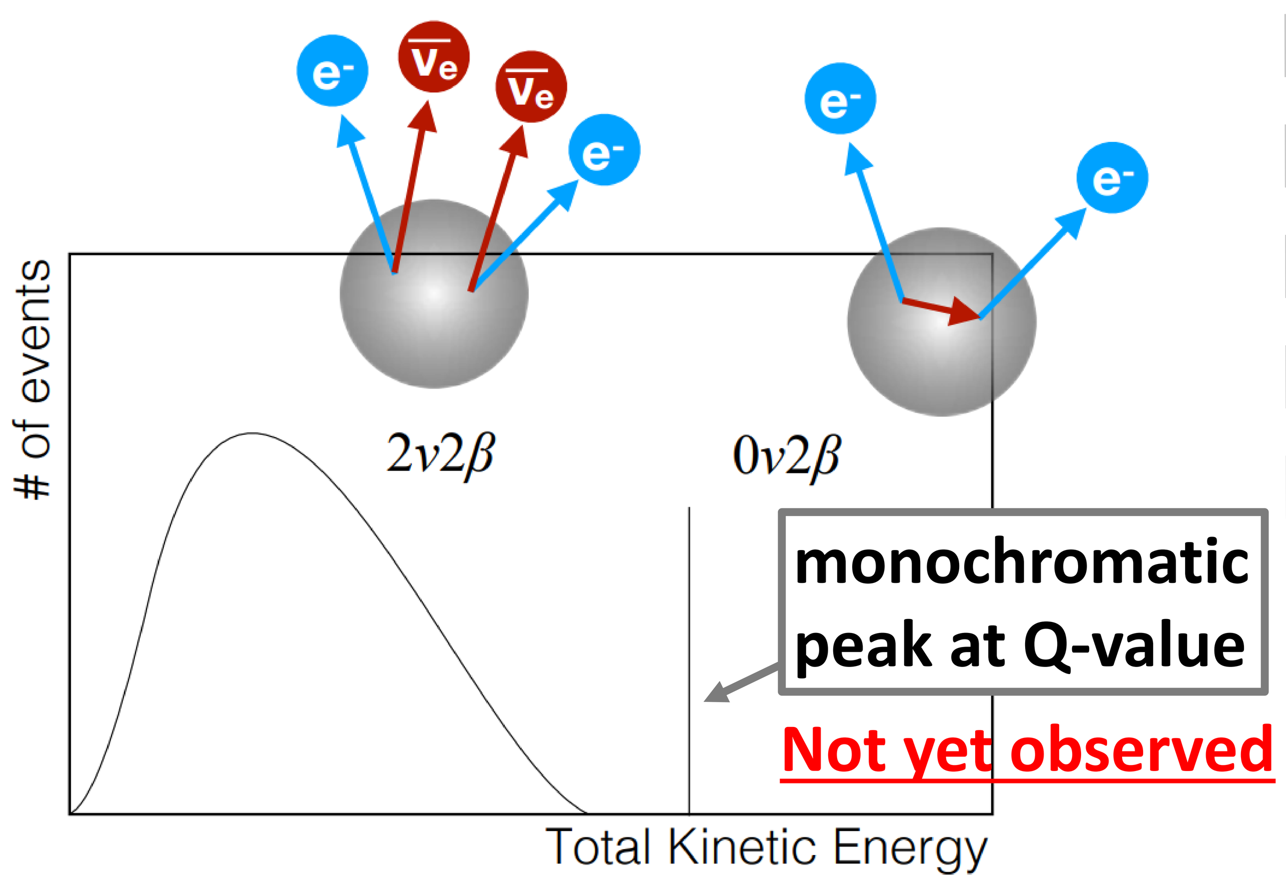
Double-beta decay



Neutrinoless double-beta decay (0ν2β)

- Special mode of double-beta decay
- Proof of **Majorana nature of neutrino**
- Measurement of **neutrino effective mass**
- Determination of **neutrino mass hierarchy**

KamLAND-Zen

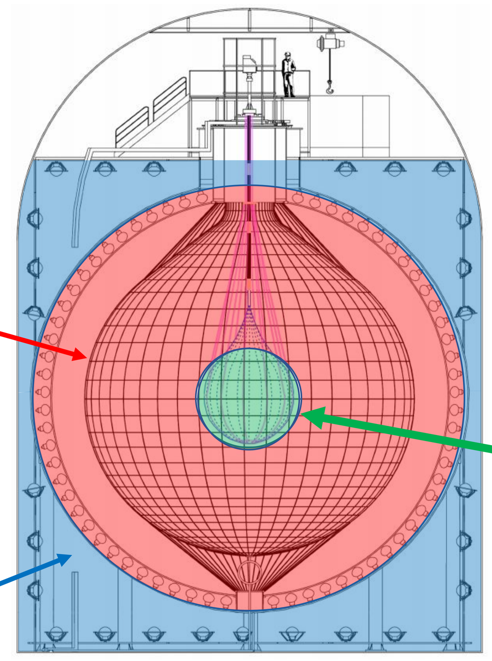
KamLAND detector

Inner Detector

- 17inch PMT x1325
- 20inch PMT x554
- Liquid scintillator

Outer Detector

- 20inch PMT x140
- Purified water

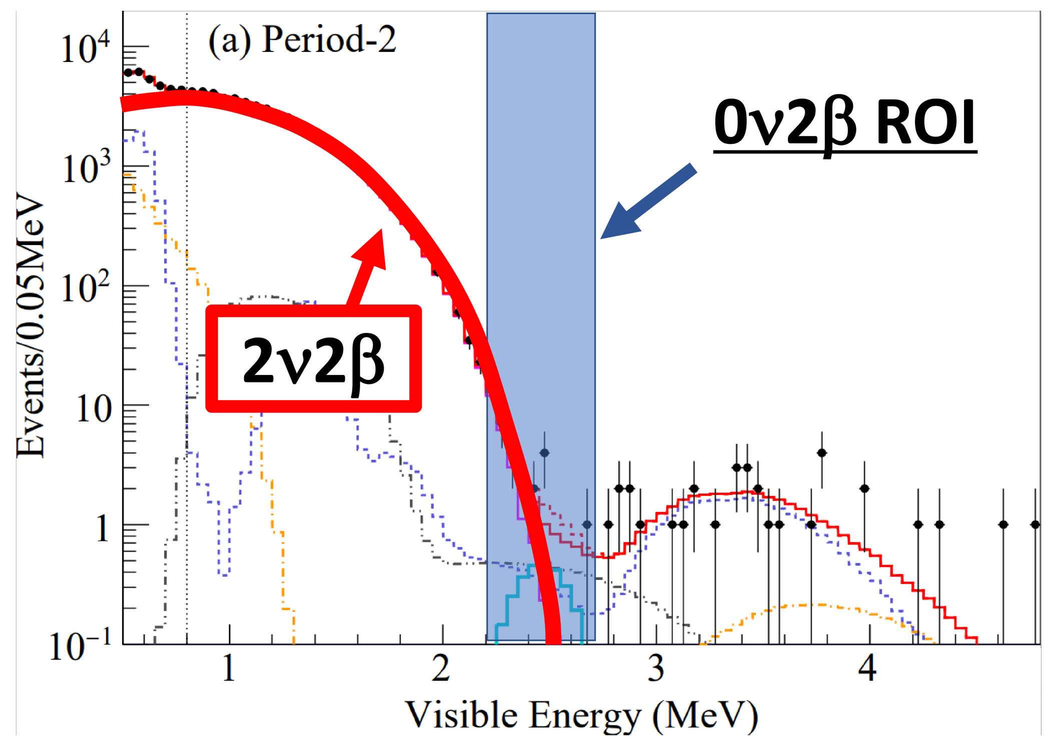


0ν2β search using KamLAND

Target isotope : ^{136}Xe (Q:2.458 MeV)

- Inner balloon
  - supporting structure
  - 25 μm thickness clean nylon
- Xenon loaded liquid scintillator
  - ~745 kg of Xenon, 90% enriched
  - 3 wt%

(KamLAND-Zen800, 2019-)



Requirement for high sensitivity

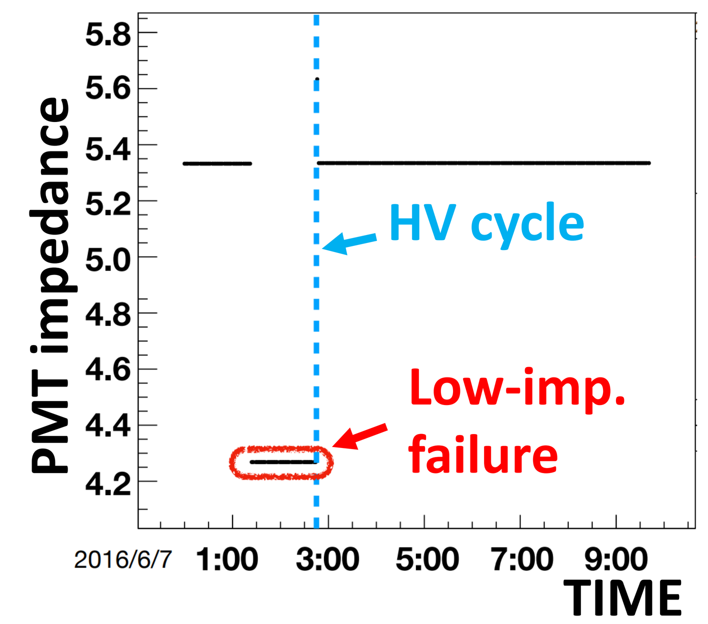
Dominant background is **2ν2β**.

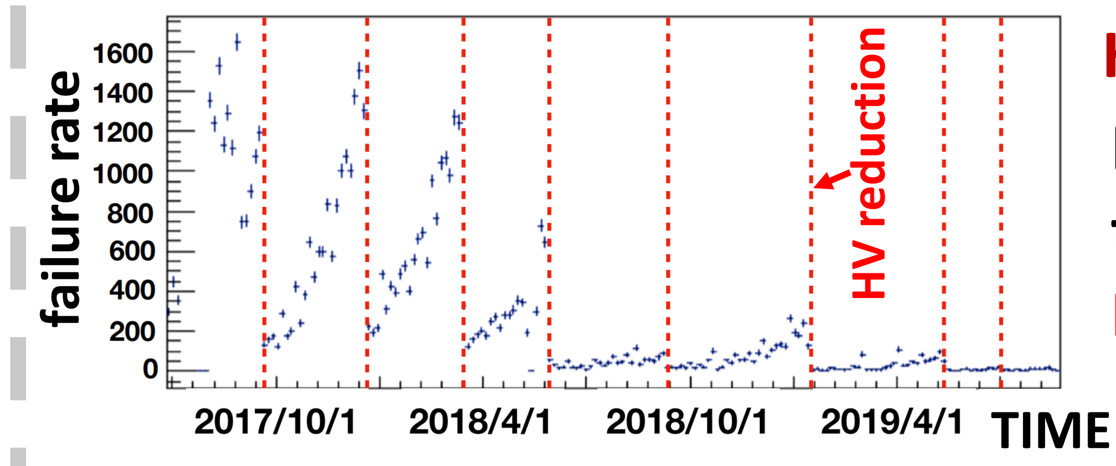
Since the only way to separate 0ν2β signal from 2ν2β is energy information, **the energy resolution plays a key role in the high sensitive search.**

Low-Gain PMT problem

Low-impedance failure of aging PMT

- Abnormal PMT impedance
- **No signal output**
- Recovery by HV power cycle
- However, **it repeats many times.**





HV reduction

Reducing HV can suppress the failure rate.

PMT gain decrease.

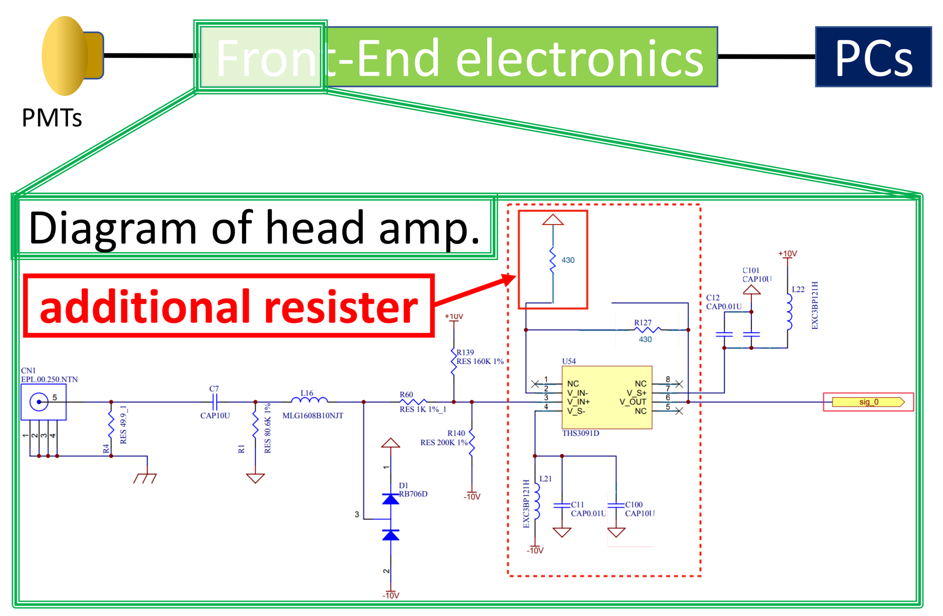
Negative effect on 0ν2β search

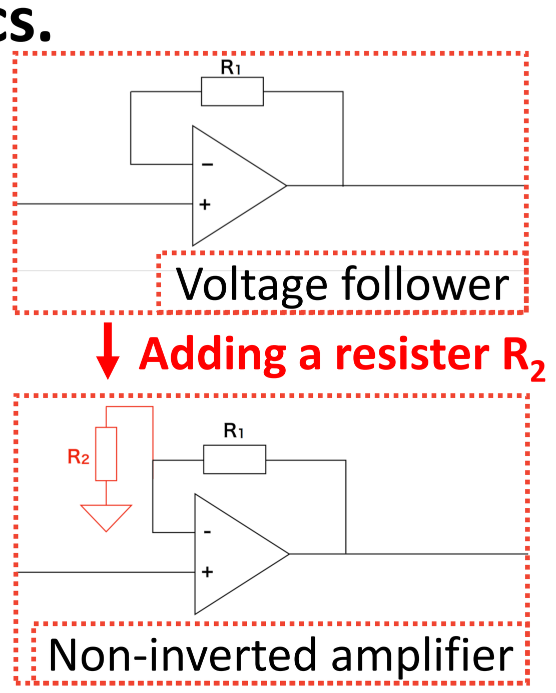
- Lower 1 p.e. detection efficiency of PMTs
- Decrease in photoelectron yield of the detector
- **Poorer energy resolution & more 2ν2β BGs in 0ν2β ROI !!**

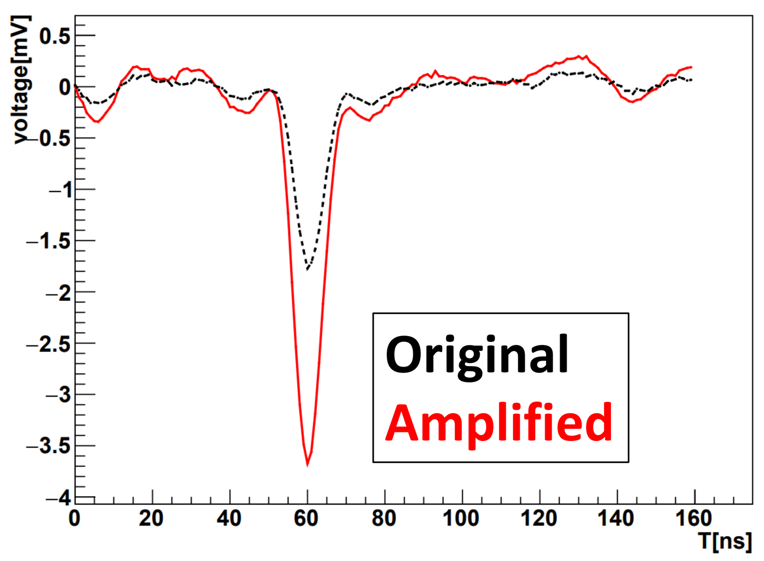
Implementation of Amplifier

How to implement the amplifier ?

→ I modified Front-end electronics.





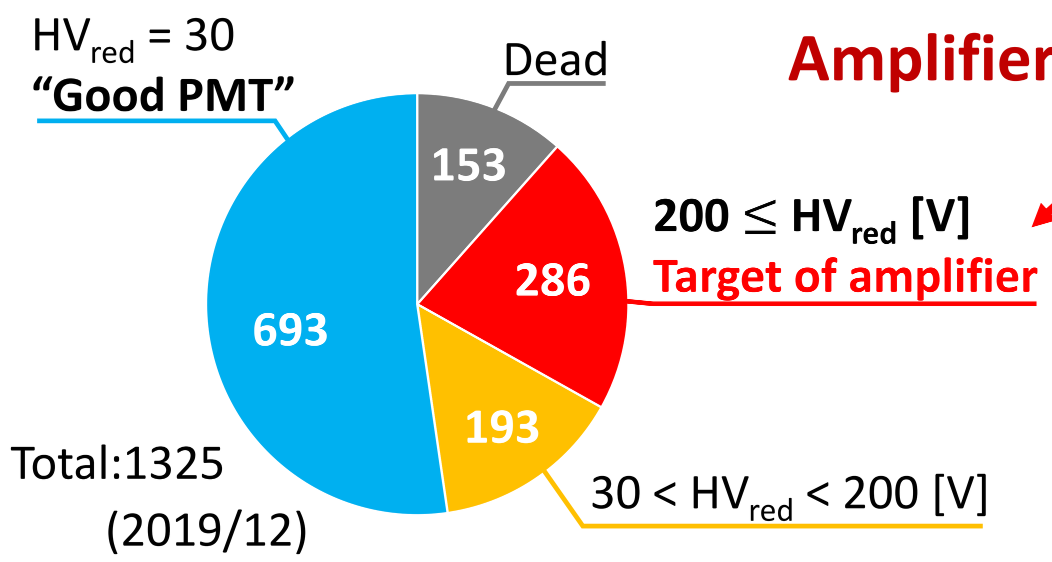


Amplification was realized only by adding a resister!!

Performance check

- Amplification works correctly.
- Baseline is stable.

Test installation to KamLAND



Amplifier's target PMT selection

Selected by the value of HV reduction (HV_{red})

Installation work

- In Nov.-Dec., 2019
- **196 of 286 target PMTs**

Evaluation of 1 p.e. detection efficiency: effective p.e.

For each PMTs,

- Expected p.e. (μ) selection : 0.5 < μ < 1.0 .
- PMT hit *N* times in such *M* events.
- #{Observed p.e.} n follow Poisson distribution $P(n;\mu_{eff})$

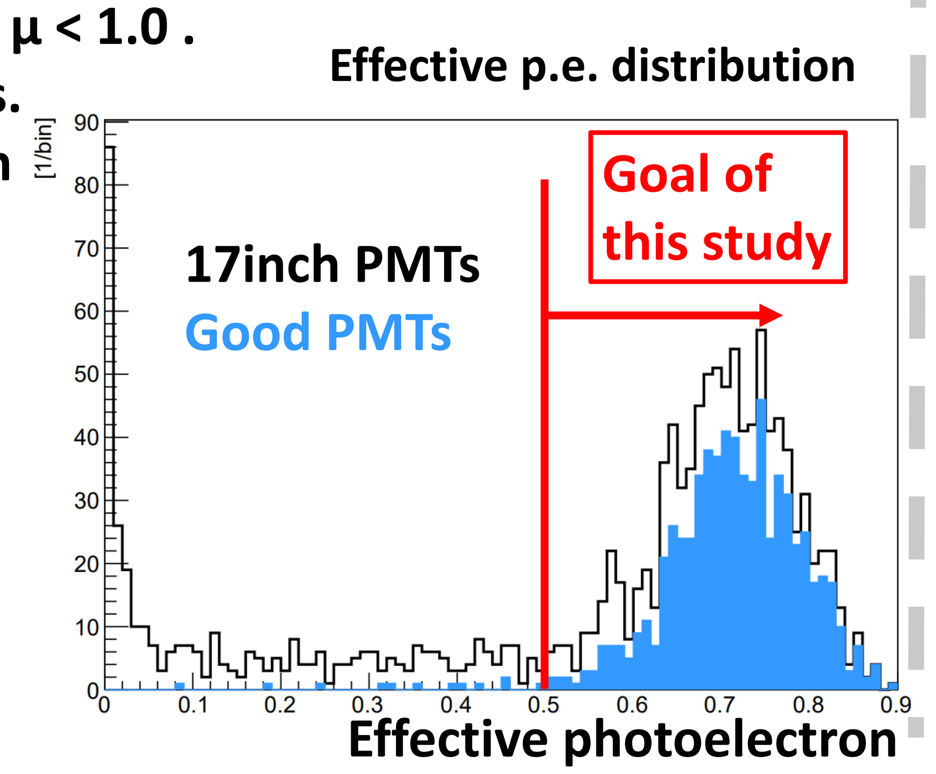
Then,

$$\frac{N}{M} = 1 - e^{-\mu_{eff}}$$

$$\mu_{eff} = -\ln\left(1 - \frac{N}{M}\right)$$

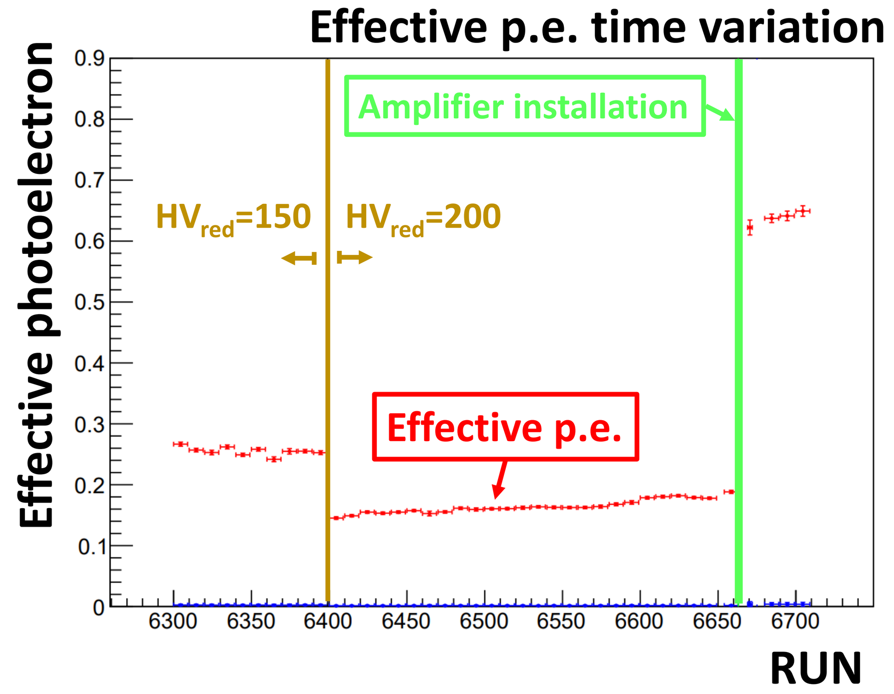
Effective photoelectron

Effective p.e. distribution

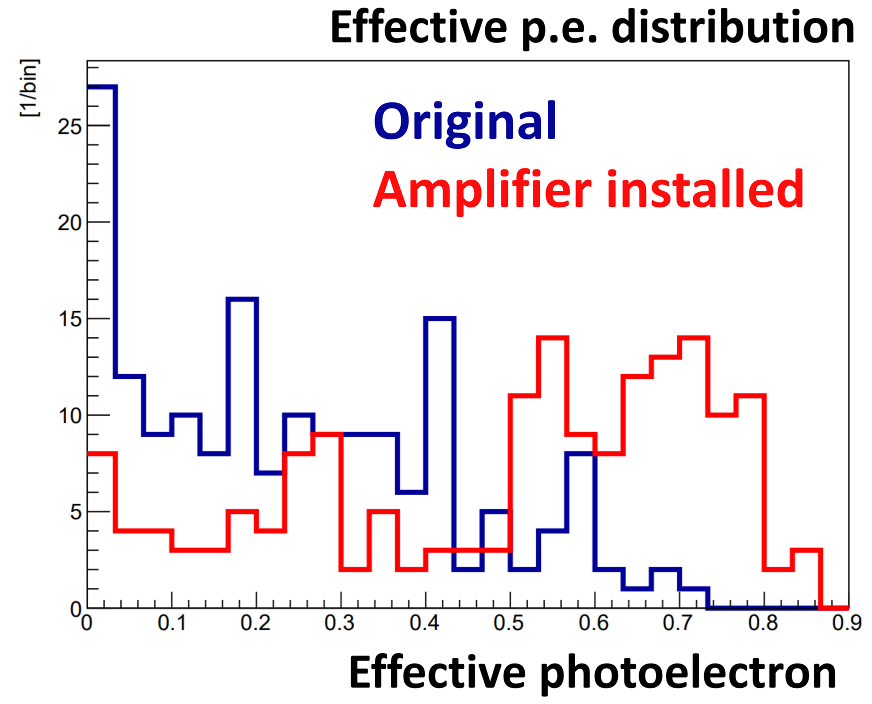


Result

Effective p.e. time variation



Effective p.e. distribution



- Effective p.e. increased by the amplifier in **180 of 196 PMTs**.
- The number of "0.5 ≤ μ_{eff}" PMT : 21/198 → **117/198** PMTs.
- Total photoelectron yield increased by **5.5%**.

Summary

- I have developed signal amplifiers for low-gain PMTs.
- It has been shown that the amplifiers can recover the photoelectron detection efficiency of low-gain PMTs.
- Detailed evaluation and analysis tool tuning are on-going.

NEUTRINO2020, Online

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