Research and development of new Front-end Electronics for KamLAND2

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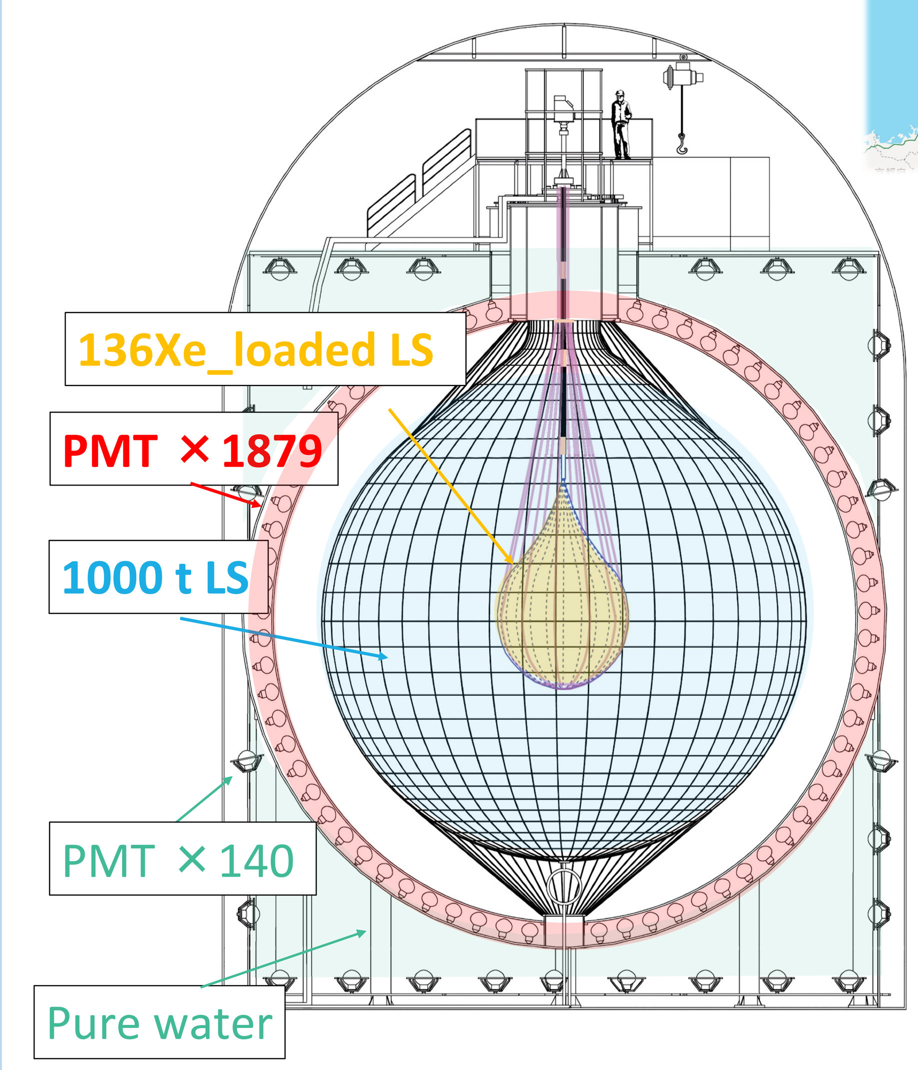
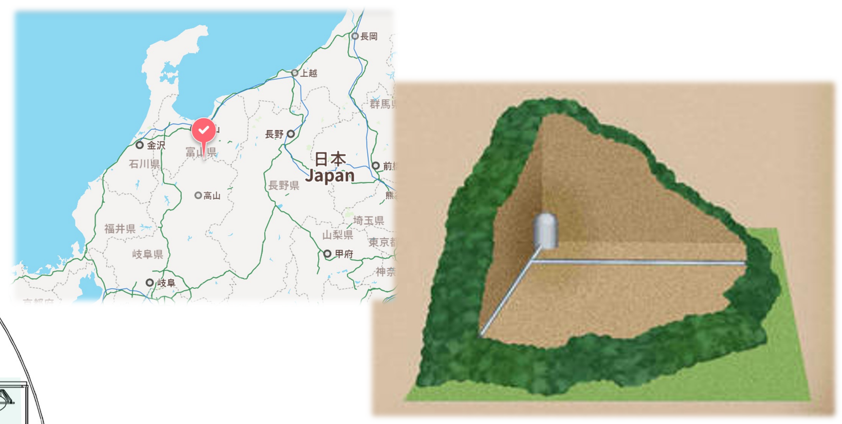
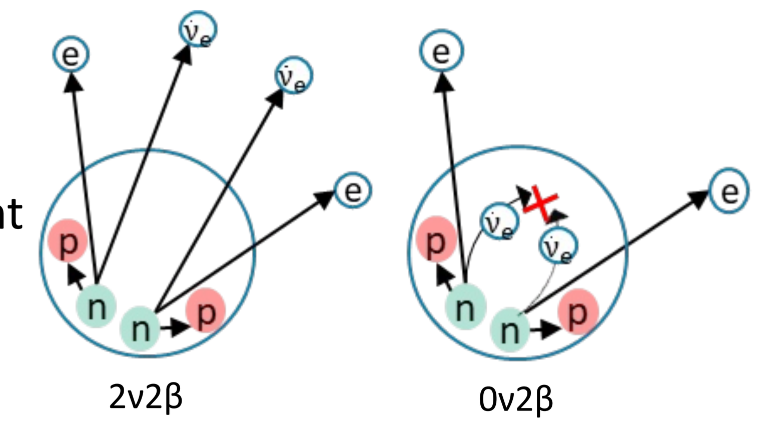
KamLAND





KamLAND detector

- At 1000 m underground in Kamioka-mine.
- Neutrino detection in **ultra low radioactive** environment
- **1 kt liquid scintillator**
- Measurement of the scintillation light with 1879 PMTs

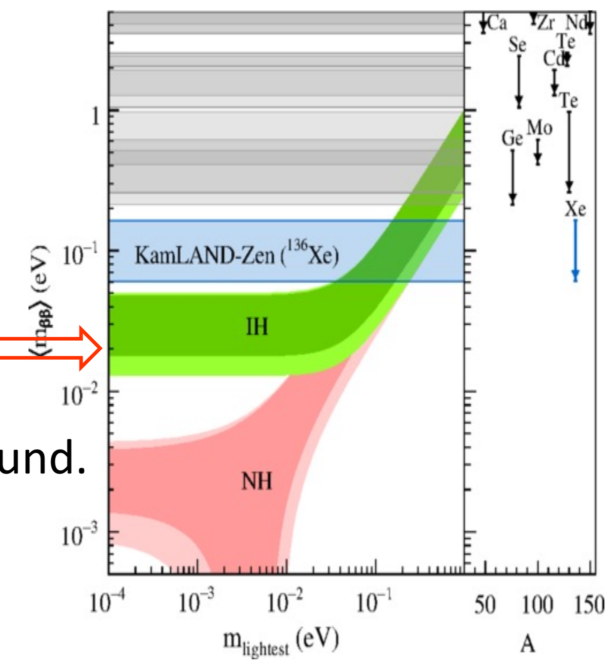


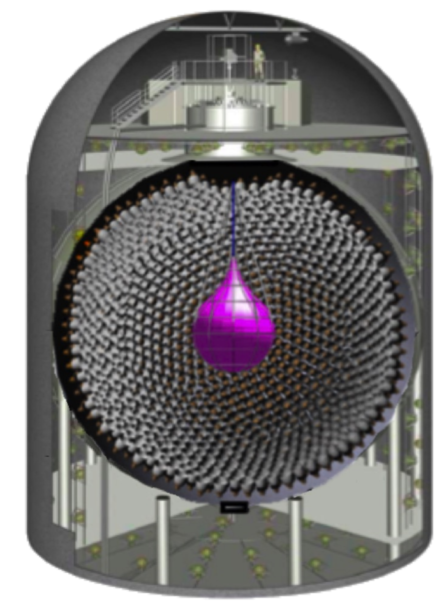
Majorana nature of neutrino

- **KamLAND searches for the neutrino-less double beta (0νββ) decay**
- 0νββ is the only realistic way to verify whether neutrinos are Majorana particles or Dirac particles.
- KamLAND uses of 745 kg xenon enriched in 136Xe

KamLAND2

- KamLAND2 is a future plan with better energy resolution against 2ν2β background.
- The goal of KamLAND2 is to reach the sensitivity which covers IH.
- Many R＆Ds are ongoing such as **new FEE**, DAQ, LS, mirror, balloon.





Motivation for new FEE

Detection of all the neutron events caused by spallation products

- The number of neutrons created by the spallation products is an important parameter.
- PMTs make overshoot and afterpulses when muons incidents on the LS.
- We need to detect all the neutron events but it is difficult for KamLAMD, because of the small size of the buffer on the electronics.

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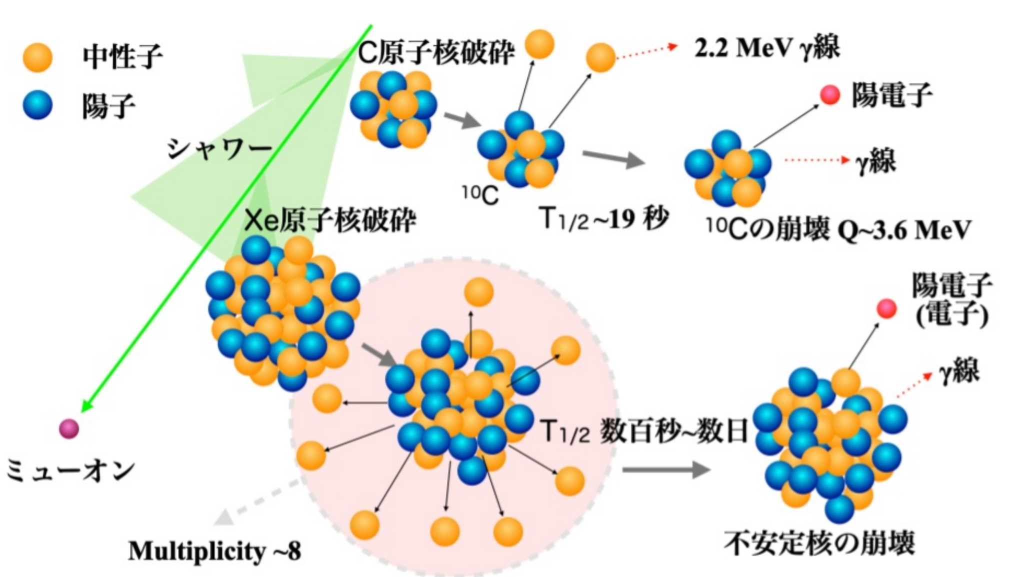
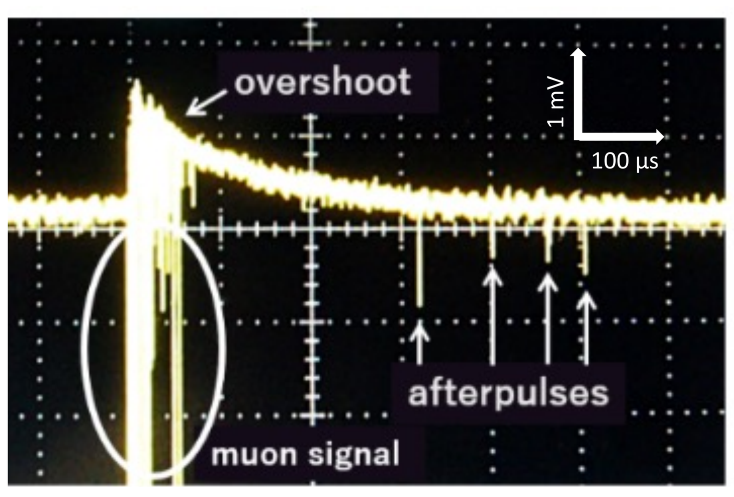
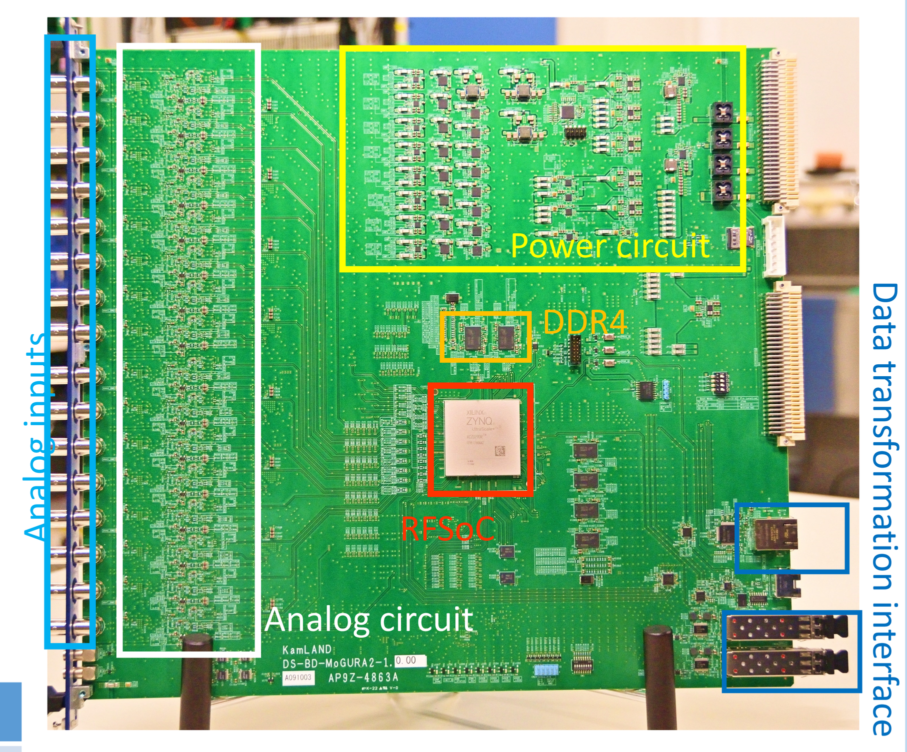
Radio Frequency System-on-Chip (RFSoC) based front-end electronics





RFSoC based Front-end Electronics

- **Xilinx Zynq®Ultrascale+™ RFSoC** is the latest FPGA family from Xilinx, which involves ADC, DAC and CPU.
- We can develop the FEE speedily and use the resource of the latest FPGA.
- **DDR4** is for the large on-board buffer.
- Each analog input is divided into two gain channels, **H-gain** and **L-gain**.



	KamLAND	KamLAND2
The number of channels	12	16
Board size	9U (366.7 mm ×400.0 mm)	
FPGA clock	50 MHz	125 MHz
FPGA built-in memory	1.26 MB	7.5 MB
On-board buffer	64 MB	4 GB (DDR4)
Data transfer	VME bass	Ethernet

	H-gain	L-gain
Target	1 – 50 p.e.	Muon
ADC	RF-ADC	ADS42LB69
Sampling rate	1 Gs/s	250 Ms/s
Resolution	12 bit	16 bit

Basic performance evaluation

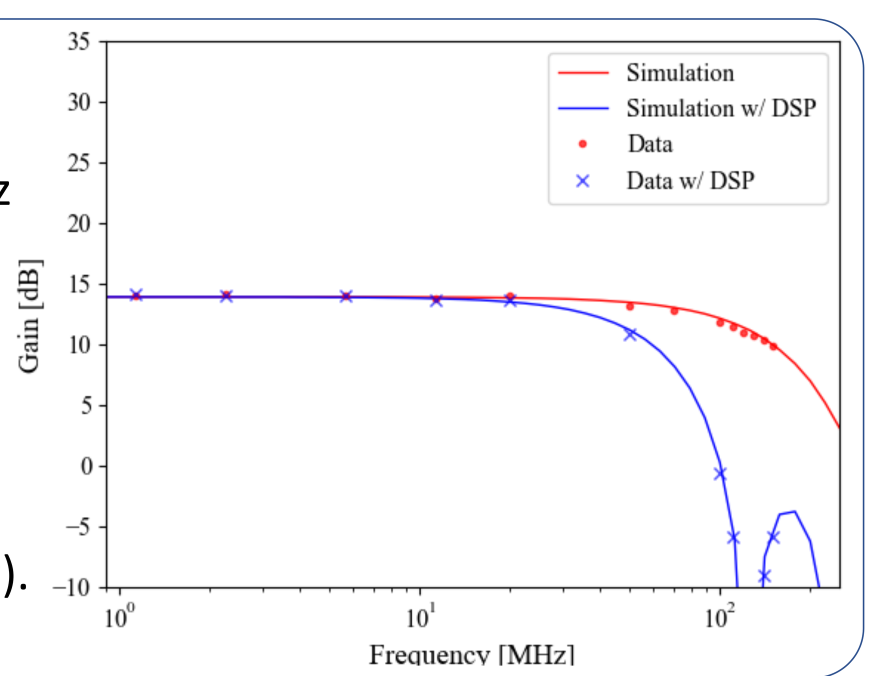
- We focus on H-gain channel and evaluate the basic performance of 6 items.

Frequency response

- The band width of the PMT signal ≃ 60 MHz

➡ **Flat frequency response below 60 MHz is required.**

- A low pass filter is also desired to reduce high frequency noises. Optimization is provided from digital signal processing (DSP). 8 ns moving average is applied in DSP.

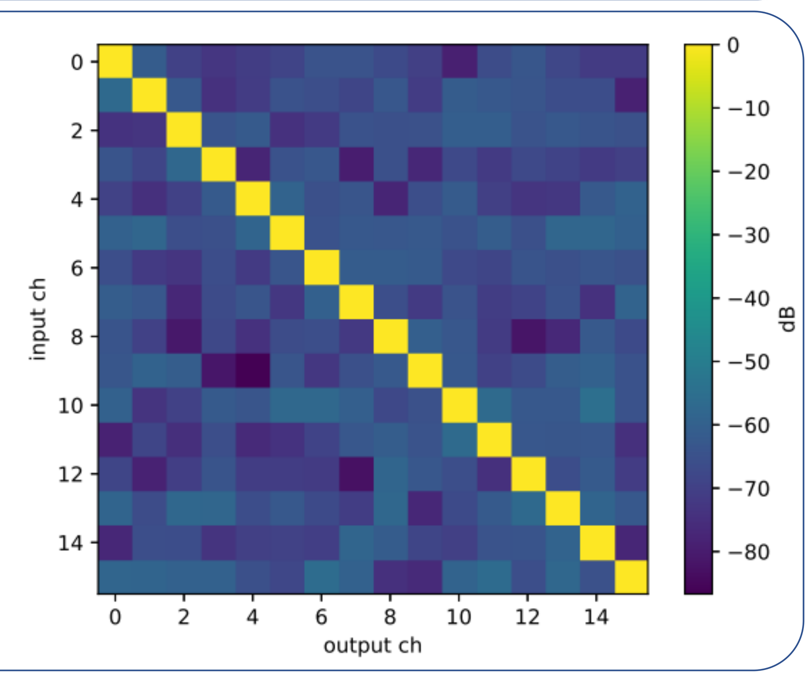


Crosstalk

- The amplitude of muon is 2 V
- The amplitude of 1 p.e. is 3 mV
- $20\log\frac{3\mathrm{mV}}{2\mathrm{V}} \simeq -55$ dB

➡ **The crosstalk should be smaller than -55 dB not to generate fake single photoelectrons.**

- We measured the amplitude of all channels when inputting sine waves each channel.

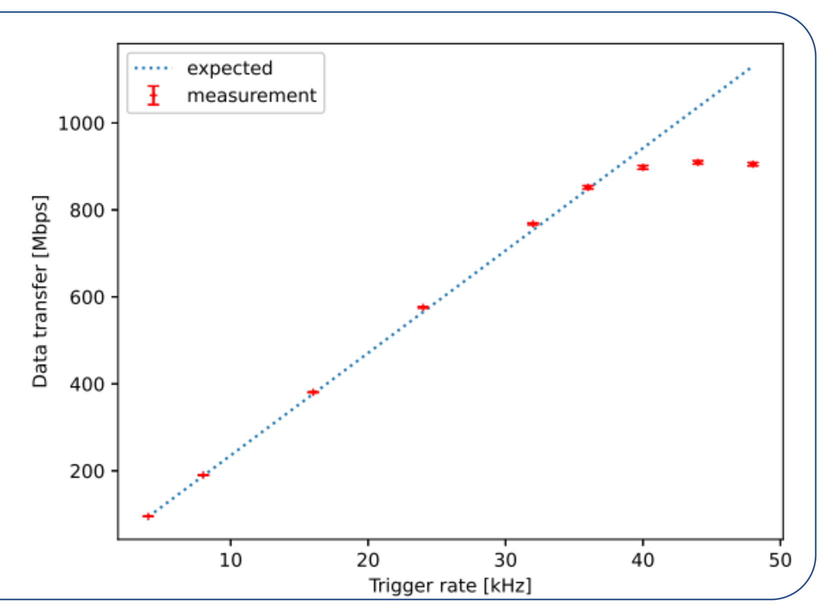


Data transfer

- The length of one event is 80 ns → 184 byte
- Dark rate of PMT is typically 20 kHz
- 184 byte × 20 kHz × 16 ch ≃ 600 Mbps

➡ **The data transfer speed should be more than 600 Mbps**

- We evaluated the data transfer speed with external triggers.

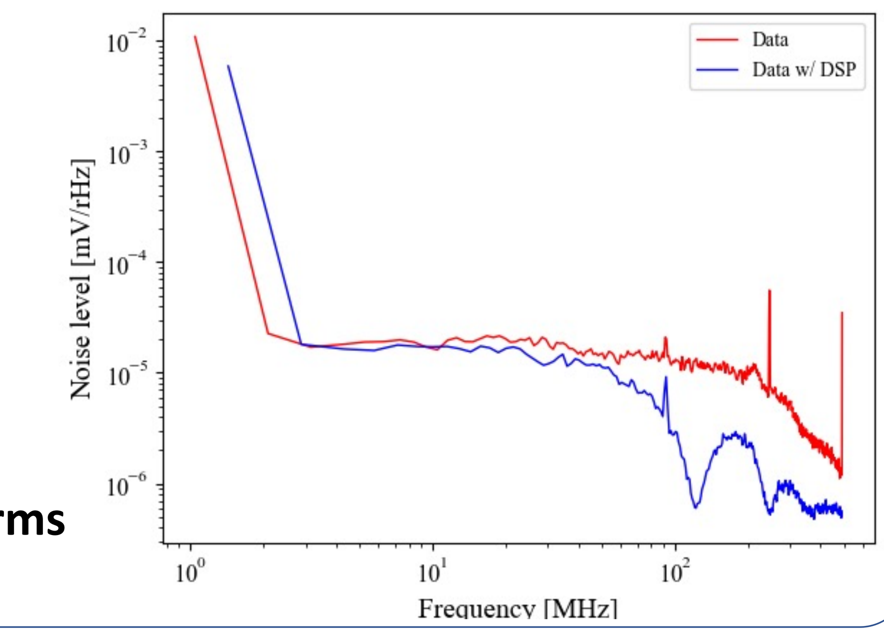


Noise level

- The high frequency noises might prevent detecting single photoelectrons.
- The amplitude of 1 p.e. is 3 mV.

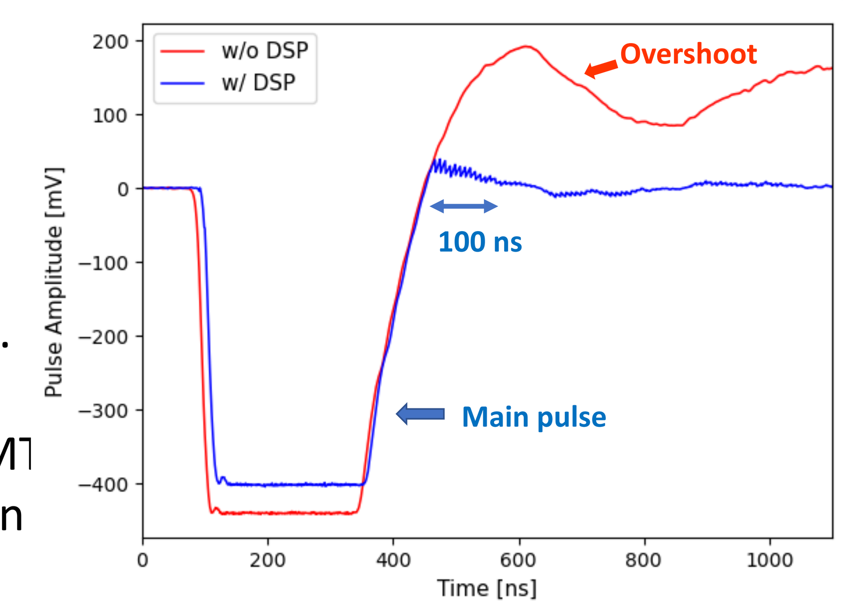
➡ **Required noise level for input equivalent < 0.3 mVrms**

- The noise level we measured is **0.17 mVrms**



Baseline correction

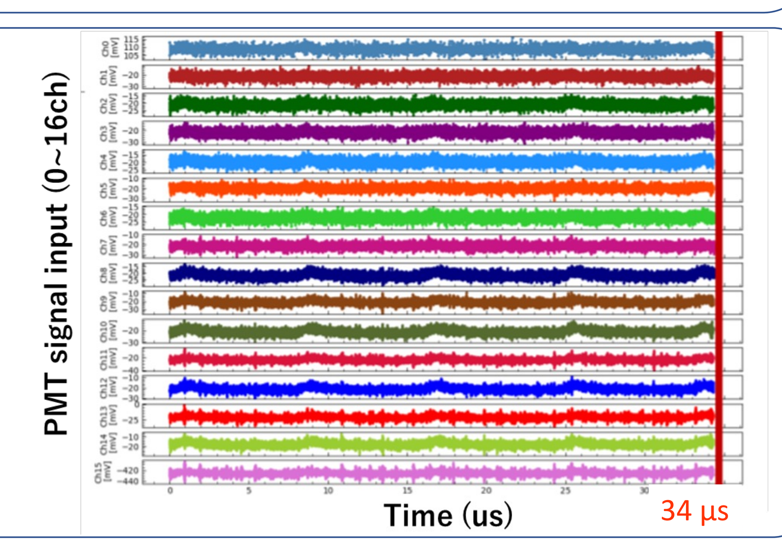
- Baseline is restored during overshoot by on-board signal processing.
- We validate the baseline correction function implemented in the DSP module.
- We measured the time for restoring baseline after a large light signal into a PMT
- We confirmed that the baseline correction does not alter the PMT signal waveform.



Continuous data acquisition

- We need to record all the waveforms including afterpulses and neutrons signals by the large buffer.

➡ **Acquiring the continuous waveform data for 10 μs is required.**



Summary and Next step

- RFSoC based Front-end Electronics is being developed for KsmLAND2.
- H-gain performances of RFSoC based FEE meets our requirements for KamLAND2.
- We are developing L-gain for muon and we will test the performance of it.