# Application of the RNN in the Fundamental Physics with KamLAND Experiment

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## Abstract

The development of the machine learning in recent years has begun to benefit the fundamental physics research. In the neutrino detector "KamLAND" aims to unravel the mysteries of the universe, discriminating gamma-ray that inhibits the signal has been ultimate task. This research made it possible by using recurrent neural networks (RNN).

## Introduction

Neutrinos are a kind of elementary particles, and their masses are hardly understood except that they are extremely light. As one of the mysteries of neutrinos, there is the possibility that the particle and anti-particle are the same property (Majorana). It is possible for only neutrinos to have this property, which is a clue to unravel the mass of neutrinos and mystery of matter dominant universe.

Majorana property is verified by detecting characteristic energy peak of the neutrinoless double beta decay (0νββ) of nuclei. A experiment to realize this is KamLAND-Zen in Japan. KamLAND-Zen measures radiation energy by detecting liquid scintillation light with optical sensors.

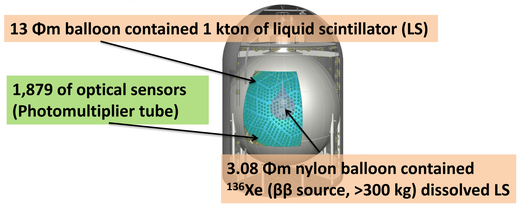



**Figure 1.** KamLAND-Zen detector

Although 0νββ decay has not been found yet in KamLAND-Zen, it has the lower limit of 0νββ half-life ($1.07 \times 10^{26}$ yr, 90% C.L.), which represents the difficulty of 0νββ decay. In the measurement, the $^{10}$C decay background (included in "Spallation" in **Figure 2**) event has the same energy as 0νββ, which hinders the observation. The identification of $^{10}$C decay is important to discovery 0νββ signal.

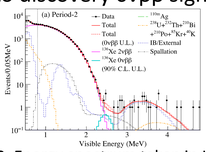



**Figure 2.** Energy spectrum taken in KamLAND-Zen[1]

## Methods and Materials

For 0νββ decay, $^{10}$C decay includes γ-rays which has a spread in time, and it is reflected in the scintillation waveform (**Figure 3**).

In addition to this, ~50% of $^{10}$C decay have ortho-positronium (oPs) which half-life is ~2.9 ns in LS [2,3,4]. In this research, $^{10}$C decay is identified by discriminating the scintillation waveform difference using "Recurrent Neural Networks (RNN)".

* ~50% of $^{10}$C decay have para-positronium (pPs) which half-life is short (<125 ps).

**【Neural networks】**

RNN is strong in time series data. RNN has a problem that learning can not proceed if input data is long (Gradient Vanishing Problem). "Long short-term memory (LSTM)" is a kind of RNN which improved gradient vanishing problem. 2-layers stacked LSTM (8 units x 2 layers) is used to classifier event type ($^{10}$C-oPs, $^{10}$C-pPs, ββ) in this research.

**【Training Data】**

Neural networks require the large amount of the training data. In this research, training data was generated in large quantity (15,000 samples x 3 event type x 20 energy bins) using well-tuned Monte Carlo Method (MC, **Figure 4**).

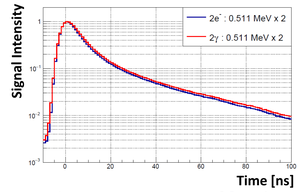



**Figure 3.** Comparison of β and γ scintillation (MC)

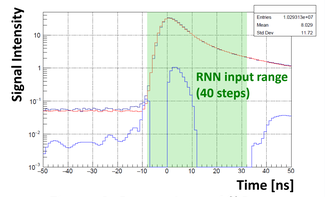



**Figure 4.** Comparison of $^{60}$Co MC and Data (Data-MC)

## Results

**【Performance Evaluation】**

The conditions of $^{10}$C identification is decided from classifier output distributions (**Figure 5**). It shows that each event type has a different distribution. If ββ inefficiency ~20% is allowed, $^{10}$C decay events are able to be rejected with ~55% efficiency (**Figure 6**). In this evaluation, MC samples are used.

**【Comparison of MC and Data】**

Since Efficiency/Inefficiency are evaluated by MC, support by Data is necessary. $^{60}$Co source calibration Data (γ-ray) is useful for evaluation. In comparison of MC and Data, distribution of classifier output (**Figure 7**) and rejection efficiency (**Figure 8**) are in good consistency. Efficiency/Inefficiency calculated by MC have enough confidence.

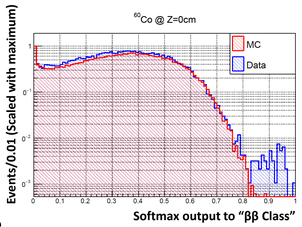



**Figure 7.** Comparison of MC and Data classifier output

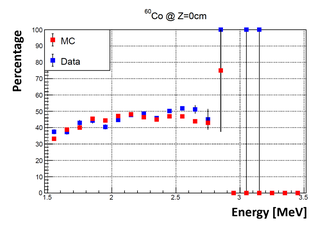



**Figure 8.** Comparison of MC and Data rejection efficiency

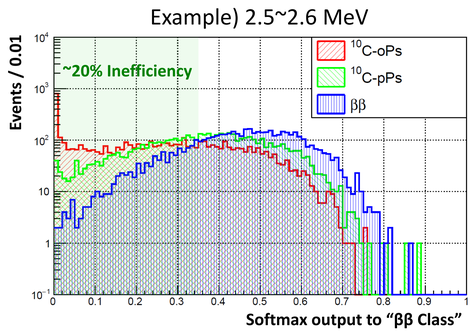



**Figure 5.** Classifier output to "ββ Class"

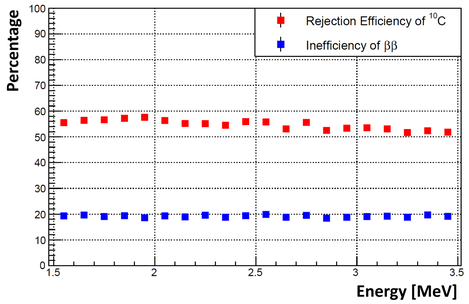



**Figure 6.** Rejection efficiency of $^{10}$C and Inefficiency of ββ

## Discussion

RNN processes the time valuation of data. It is thought that RNN which developed in this research classified the event type based on the spread of scintillation waveform. As its basis, $^{10}$C-oPs with larger scintillation spread are lower in ββ classification output than $^{10}$C-pPs in **Figure 5**.

## Conclusions

The neutrino detector "KamLAND" aims to unravel the mysteries of the universe. Reduction of $^{10}$C decay background is indispensable for verifying the Majorana property of neutrinos.

To identify $^{10}$C decay events, discriminating the scintillation waveform difference by using RNN. In this research, 2-layers stacked LSTM was developed. And then it is able to reject ~55% of $^{10}$C decay events with ββ inefficiency ~20% is allowed. From the evaluation by using $^{60}$Co source calibration data, this efficiency/inefficiency have enough confidence.

This research realizes the improvement of the sensitivity to discover 0νββ signals.

## Future Directions

At the β decay, scintillation light is isotropically emitted because β-rays deposit energy to LS. On the other hand at the γ decay, since the distance of γ-rays is long, emission direction of scintillation light has bias. It is considered that a method of identification of these event topological difference by "Convolutional Neural Networks (CNN)" is useful. However the optical sensors are arrayed at inner wall of the spherical tank. It is necessary to develop method to process spherical patterns. Although development of this method is difficult, it is able to be expected to further improvement of $^{10}$C decay background rejection efficiency.

## Contact Information

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## Acknowledgements

I would like to thank Prof. Inoue and Assoc. Prof. Shimizu for directing my research. And I am grateful to every KamLAND and KamLAND-Zen collaborators.

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