Energy Resolution Improvement for CaF_2 Scintillating Bolometer by Machine Learning Analysis

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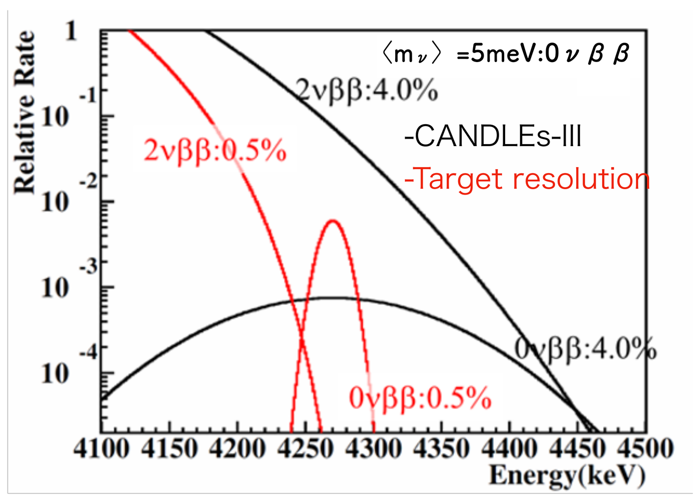
1 Introduction

- The CANDLES experiment aims to observe $0\nu\beta\beta$ decay of ^{48}Ca(4.27MeV)
- Detectors with poor energy resolution will have $2\nu\beta\beta$ decay as background(BG)

→A detector with excellent energy resolution is required to eliminate $2\nu\beta\beta$ decay BG (above figure).

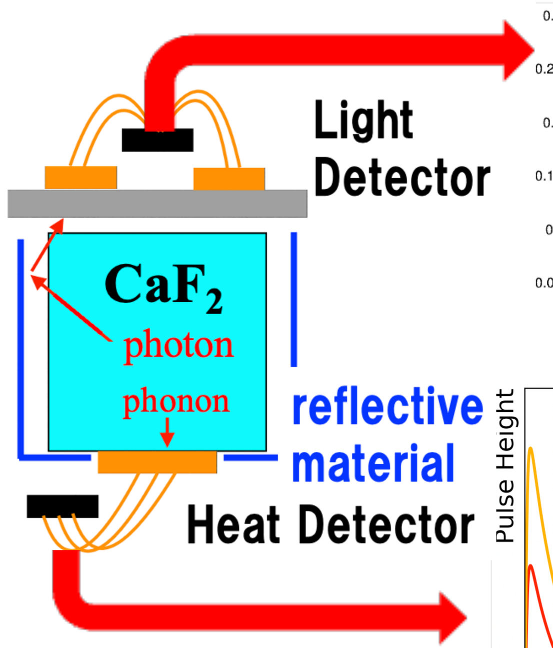


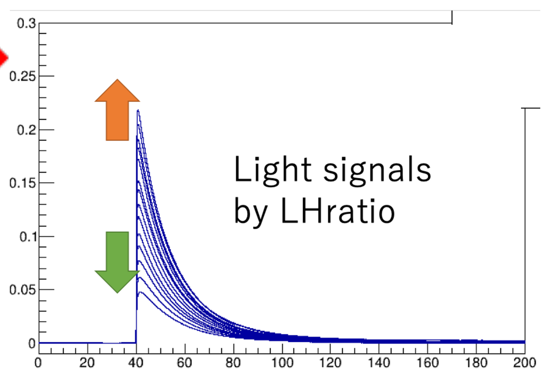
- The target energy resolution of the CaF_2 scintillating bolometer --> 0.5% @ 4.27 MeV

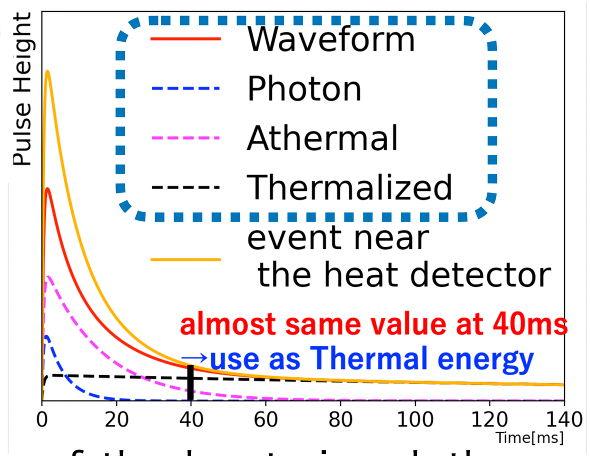
→ However, the target energy resolution is currently not achieved.

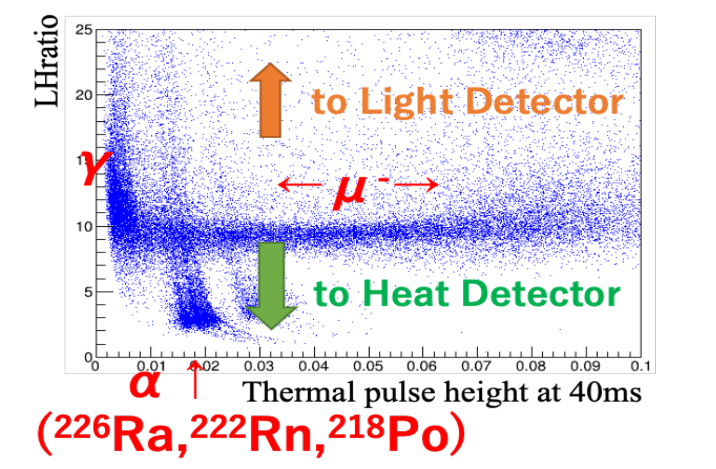
2 CaF_2 Scintillating Bolometer

CaF_2 scintillating bolometer detects scintillation light and heat generated by $\beta\beta$ decay and α ray.







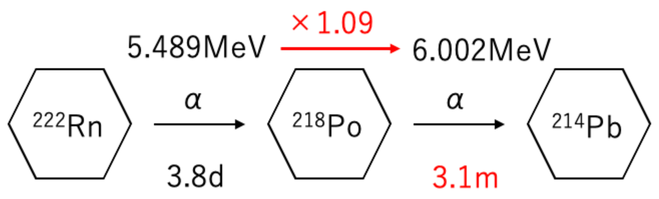


(^{226}Ra, ^{222}Rn, ^{218}Po)

Scintillation light has different pulse heights for α-rays and β,γ-rays due to the quenching effect, which enables us to identify particles by using Heat to Light Ratio (LHratio).

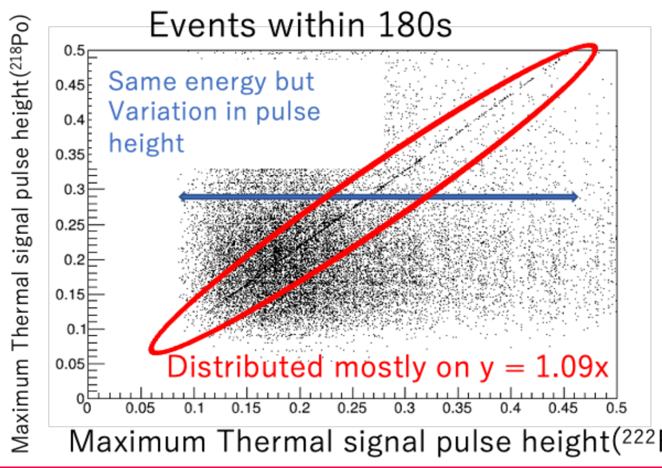
Of the components of the heat signal, the photon and phonon pulse heights have intracrystal position dependence.

→ Pulse height at 40ms is used as the energy value to remove the influence of position dependence.



The half-life of ^{218}Po is 3.1 min, which allows us to confirm the event at the same location.

For events occurring at the same location, there is a proportional relationship between the energy and maximum pulse height of the thermal signal.



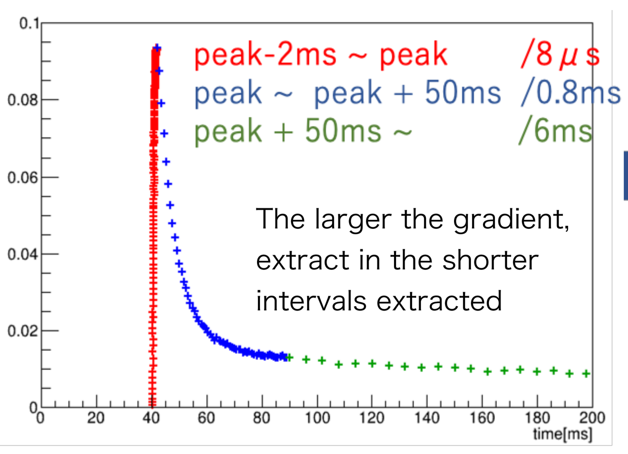
→ If the position dependence can be eliminated, the energy resolution much improved(1.8%—>0.18% at 5MeV)

Pulse height, rise time, time constant of attenuation, etc. has multidimensional correlations.

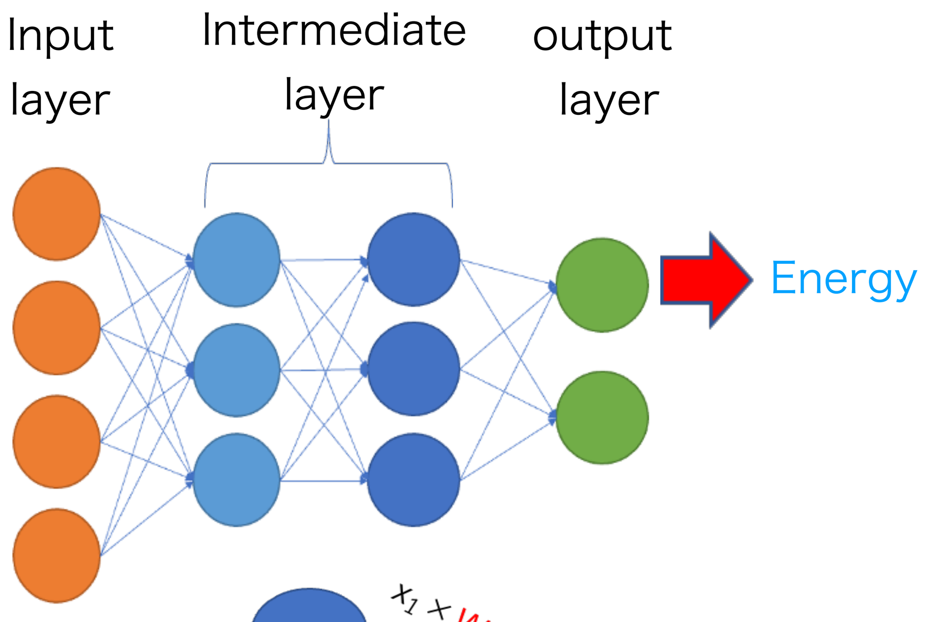
→Try to correct by **machine learning**

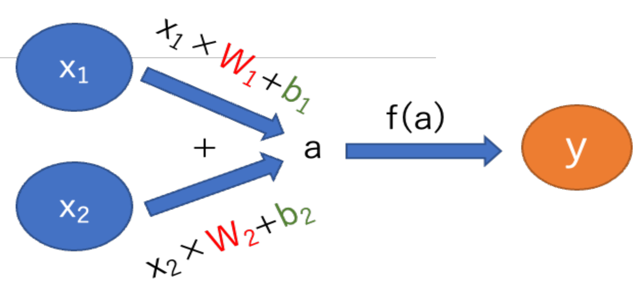
3 Neural Network

Heat and light signal data



Extract values to reduce the number of calculations(100000 -> 660 elements)





In neural network, Optimizing the weights W_i and bias b_i based on the training data.

In this study, I create a network that outputs energy when a signal is input.

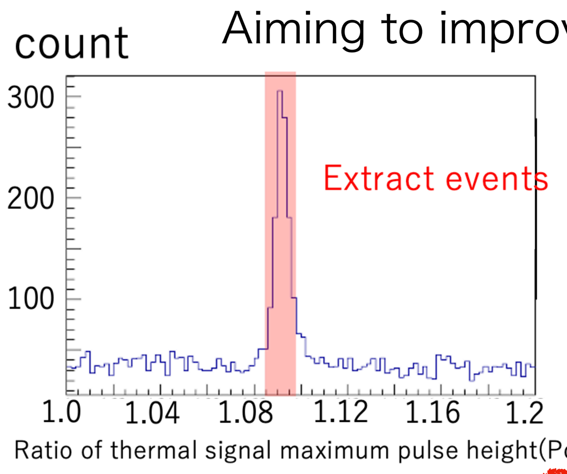
4. Machine Learning

4-1 labeled data creation

Created two sets of labeled data from different perspectives to improve accuracy.

labeled data1

Aiming to improve accuracy by making data more precise

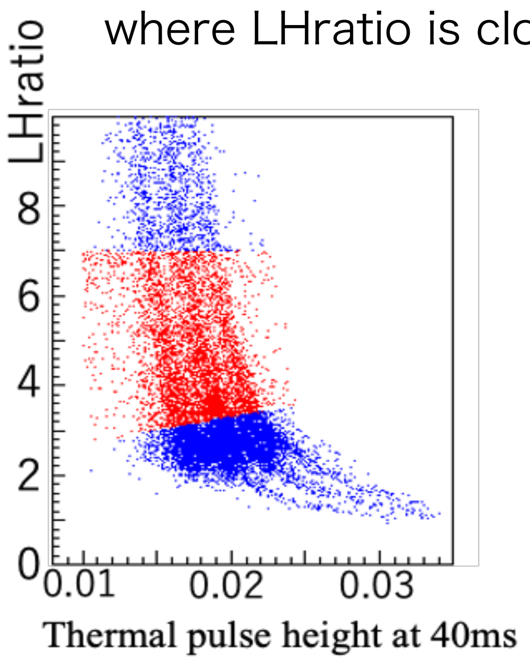


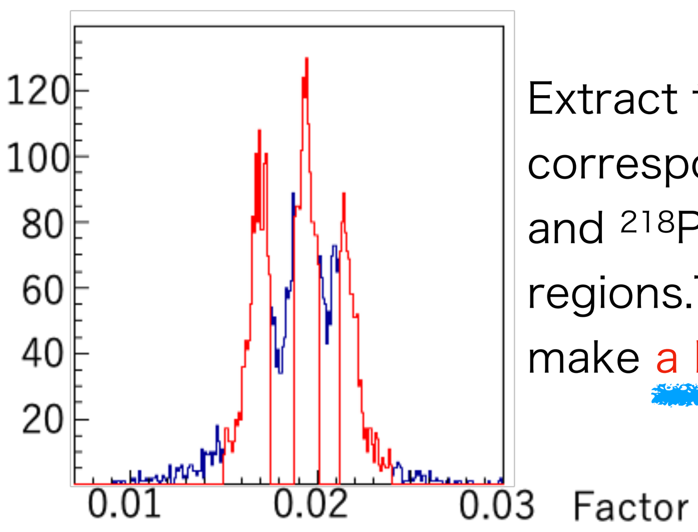
Use the ratio of the maximum pulse height of the thermal signals of Rn and Po is 1.09.

Take out where the data is almost certainly ^{222}Rn, ^{218}Po as training and test data.

labeled data2

Separate learning for each region on the graph to improve accuracy (Learning is efficient because waveforms are similar for regions where LHratio is close)

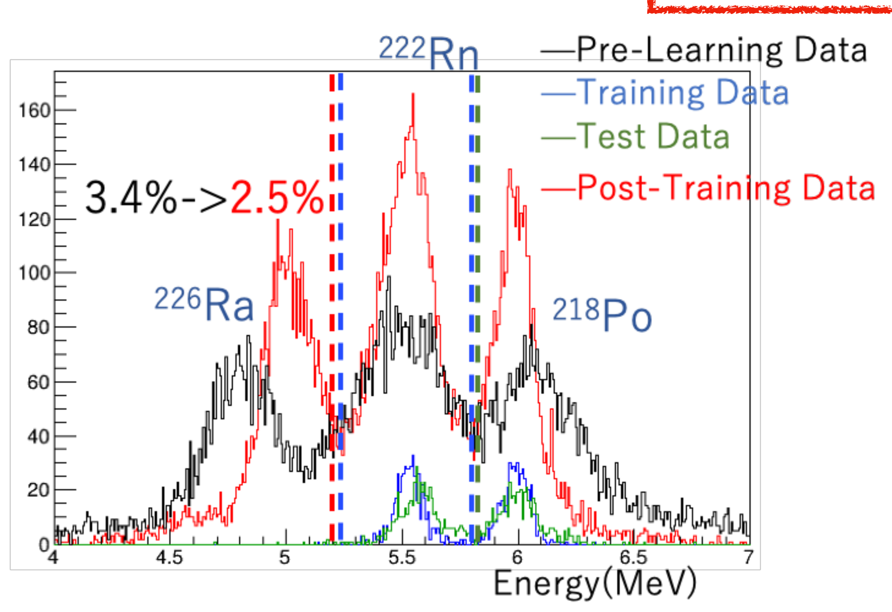


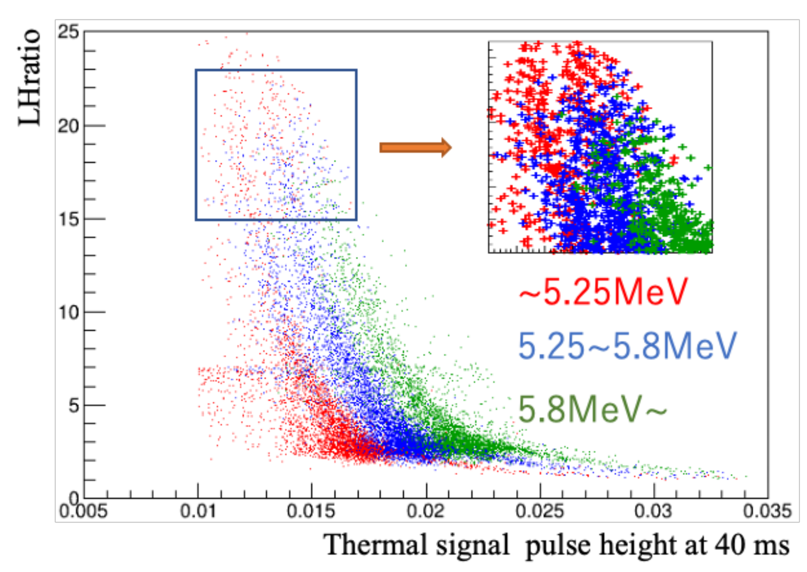


Extract the events corresponding to ^{226}Ra, ^{222}Rn, and ^{218}Po from the selected regions. This method can make a lot of training data.

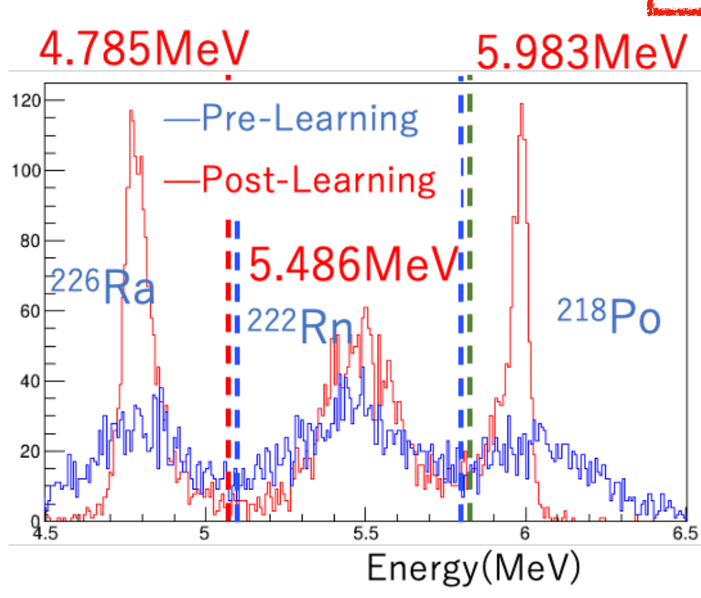
4-2 learning result

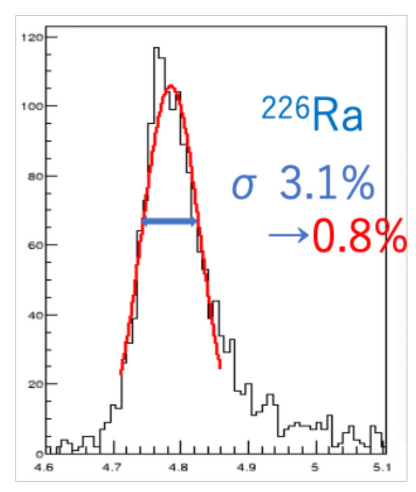
labeled data1

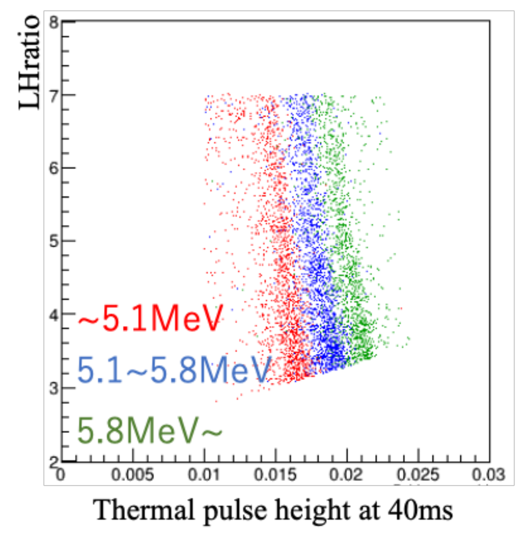




labeled data2







	data1	data2
Advantages	Success to reproduce the peak of ^{226}Ra from the training data of ^{222}Rn and ^{218}Po	The energy resolution of ^{226}Ra and ^{218}Po is very good (0.8%@4.785MeV).
Disadvantages	poor accuracy for events where light energy is large relative to heat	Poor resolution for ^{222}Rn

5. Summary

Two datasets were trained

- A resolution of 0.8% was achieved at 4.78 MeV by splitting the data.
- The training data is small, so the energies of events with high light energy relative to heat energy are not correct.
- At this time, due to the small number of training data, the energy of events with large light energy relative to heat energy is not correct, but it is possible to reproduce the peak of Ra.

6 Future Prospects

- Possibility of achieving very good energy resolution for other regions by learning separately for each region on the graph of alpha events

→Validity is checked by verifying that the correct energy is output when the waveforms of alpha events other than ^{226}Ra, ^{222}Rn, and ^{218}Po are input.

- The peak of Ra can also be reproduced from Rn and Po and may be accurately learned by further reducing noise.