Development of an R-value-Based Trigger Algorithm for Energy Threshold Reduction

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On behalf of the AMoRE Collaboration

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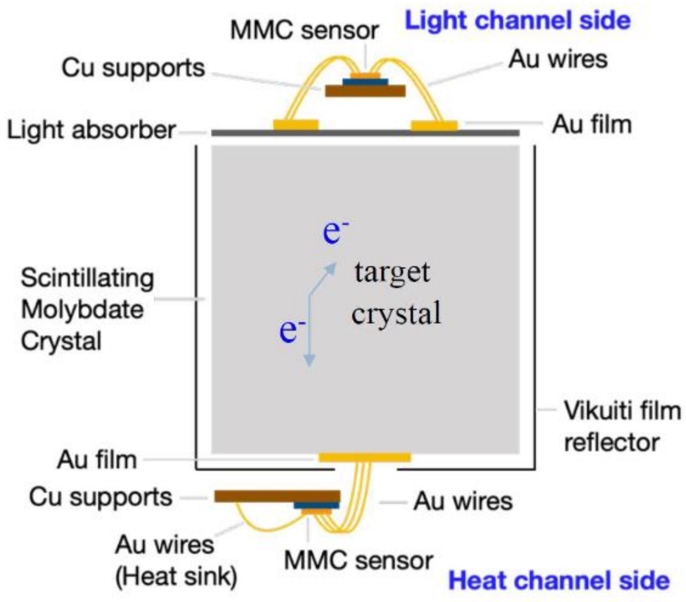
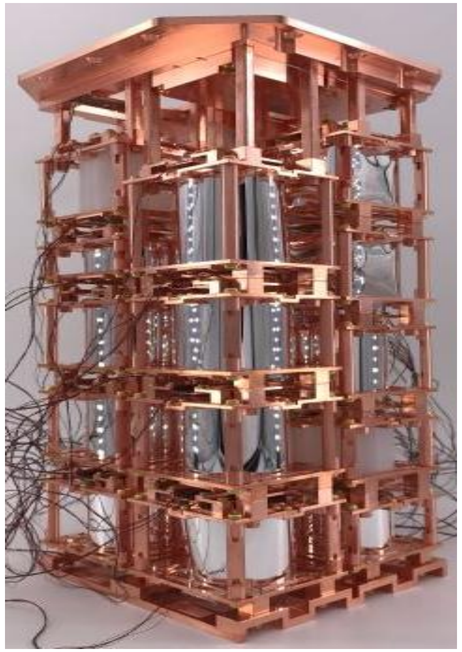
Introduction

: to achieve as low an energy threshold as possible

- LTDs(Low temperature detectors) widely employed in searches for rare processes such as neutrino interactions (2νββ, CEνNS) and dark matter (WIMP).
  - Offer low energy thresholds, wide dynamic ranges, and excellent energy resolution.
  - CRESST, CUORE, CUPID, SuperCDMS, AMoRE, …





Talk: AMoRE-II construction by SeungCheon Kim on Aug.25th
Poster: Background Modeling of AMoRE-I by B.Bhandari, etc..

Introduction

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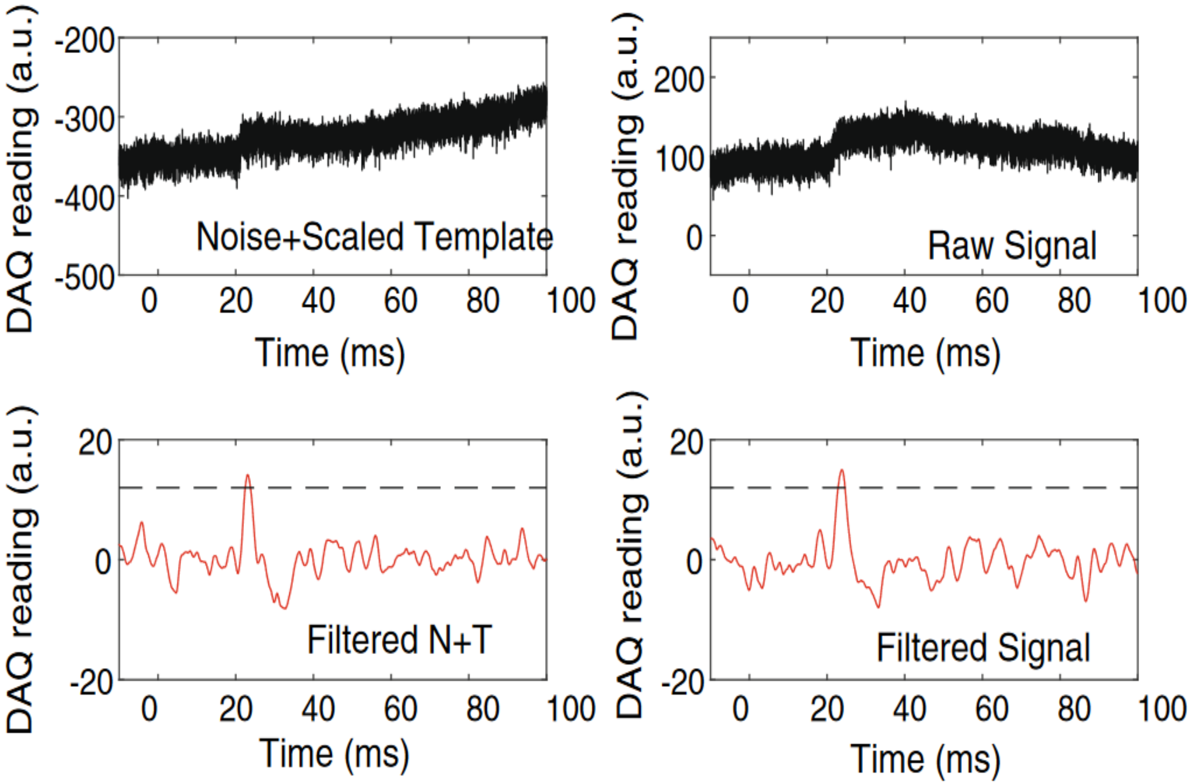
- To achieve the lowest possible energy threshold:
  - Improves background understanding
  - Expands the physics reach of the experiment
    - Possibly to study double electron capture of ^{40}Ca of $CaMoO_4$ crystal by AMoRE I&II
      - $2\nu2K$ (6.4keV), <u>$0\nu2EC$ (193.51keV)</u>
    - Dark matter search, etc…

A study of neutrinoless double electron capture of Ca-40 with the AMoRE-I experiment by Bijaya on Aug.26th

Conventional trigger (height trigger)



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- Leading edge trigger: the trigger occurs at the first crossing of a set height threshold
- Determined threshold from noise RMS
- Apply to filtering before trigger for noise reduction
    - Butterworth bandpass filter
    - Optimal filter

New trigger, r-value

: Pearson (product-moment) correlation coefficient

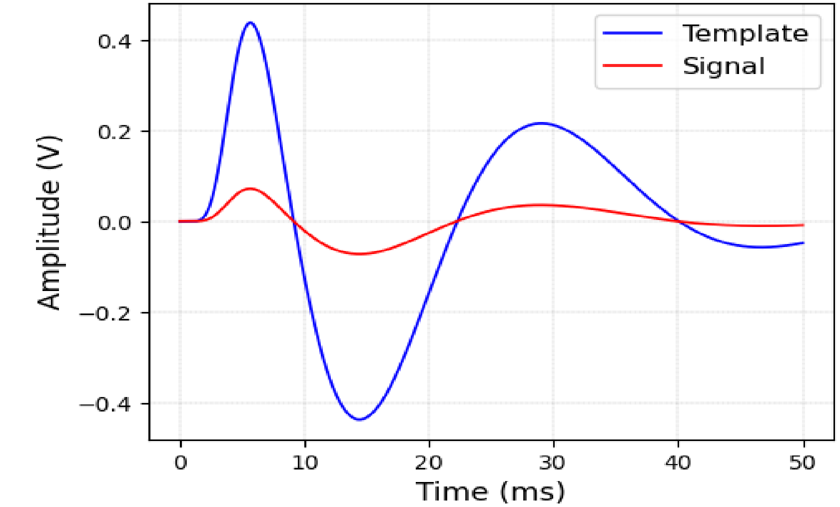
$$r_{xy} = \frac{\sum_{i=1}^{N} \delta x_i \cdot \delta y_i}{\sqrt{\sum_{i=1}^{N} \delta x^2}\sqrt{\sum_{i=1}^{N} \delta y^2}} = \frac{\sum_{i=1}^{N} (x_i - \overline{x}) \cdot (y_i - \overline{y})}{\sqrt{\sum_{i=1}^{N} (x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{N} (y_i - \overline{y})^2}}$$

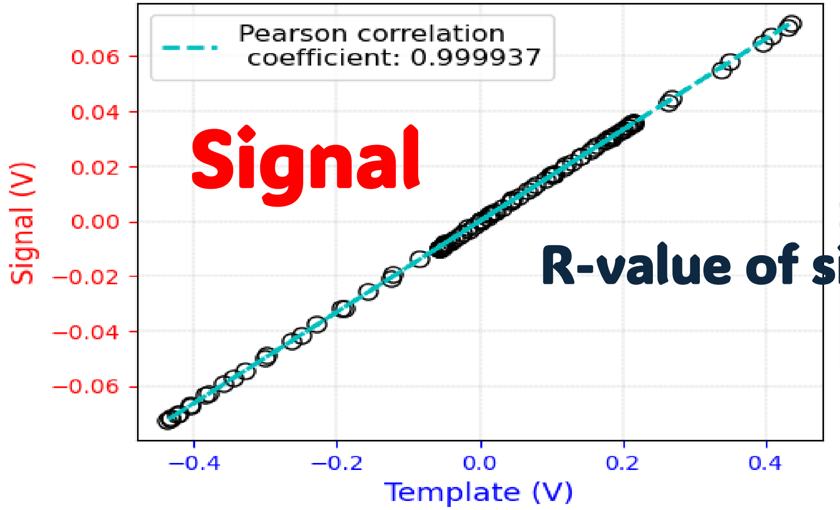
Where; x : a slice of data, y : a signal template

- Measure of Linear Correlation Between Two Variables (x, y)
- Defined as the cosine of the angle between two variance vectors,
  - $-1 < r_{xy} < 1$

New trigger, r-value

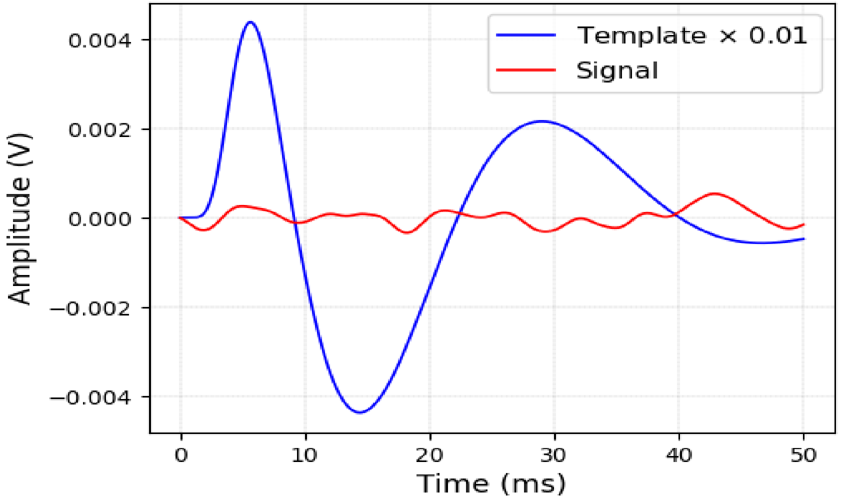
: Pearson (product-moment) correlation coeffi cient

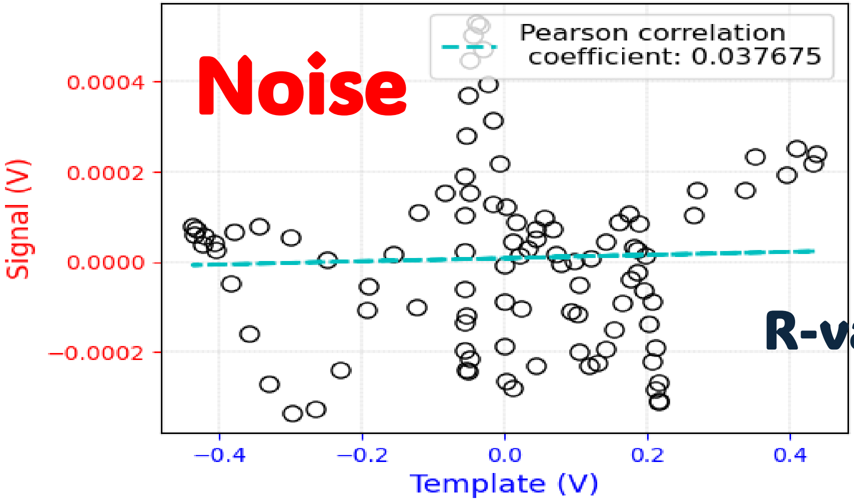




R-value of signal : ~1

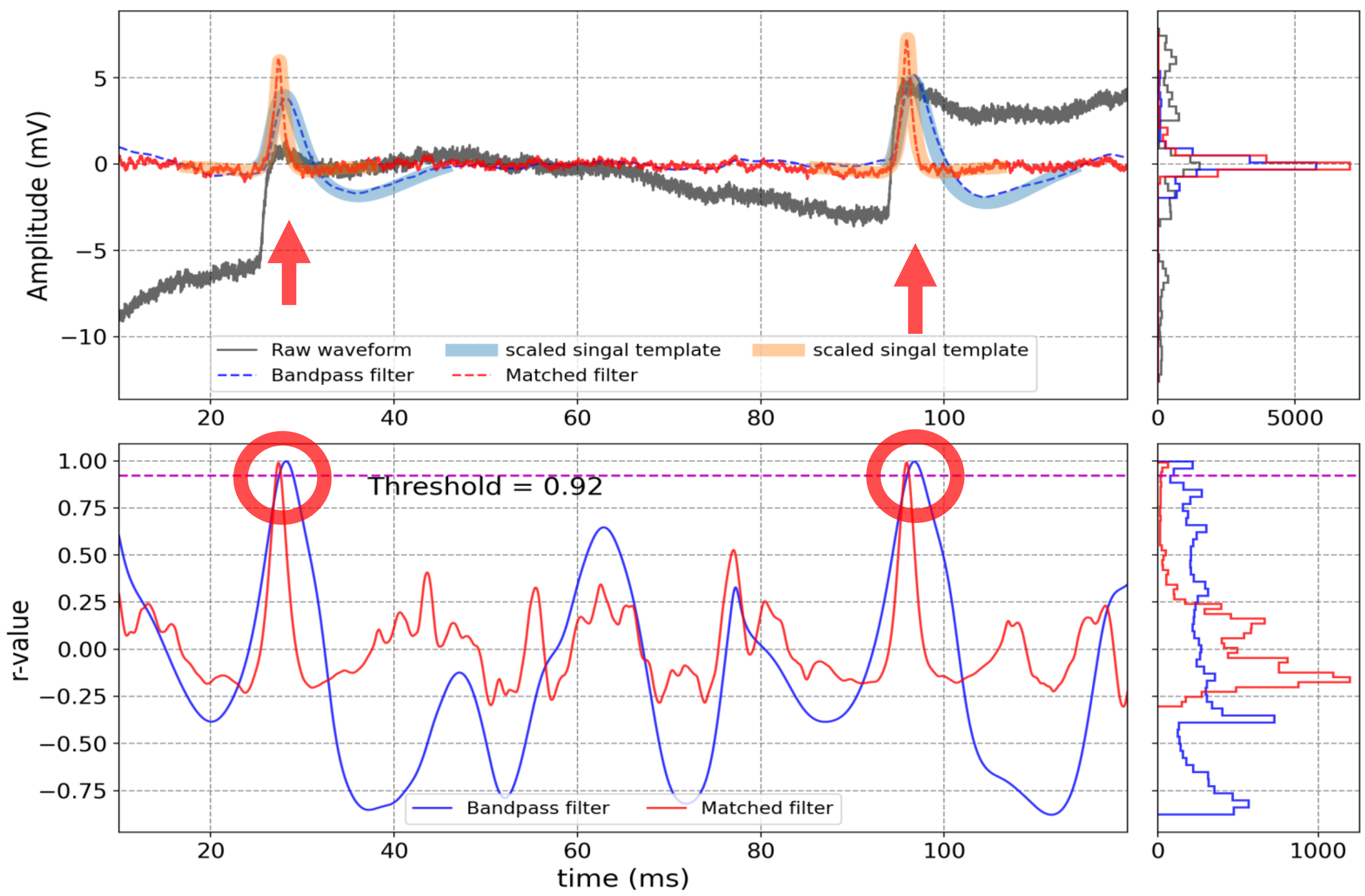
- **Butterworth bandpass filter**





R-value of noise: << 1

Example of r-value trigger process

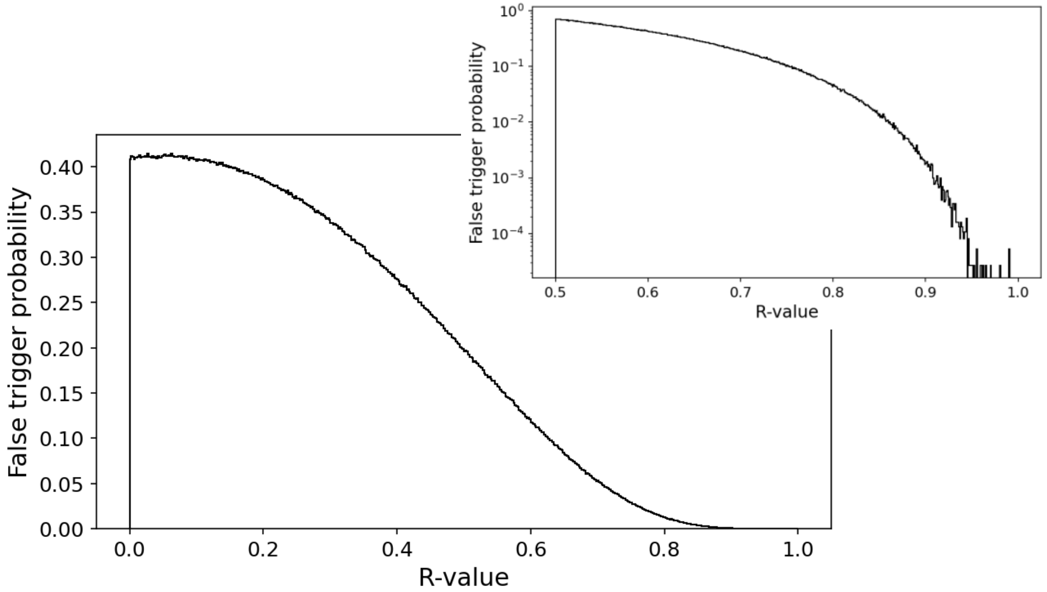


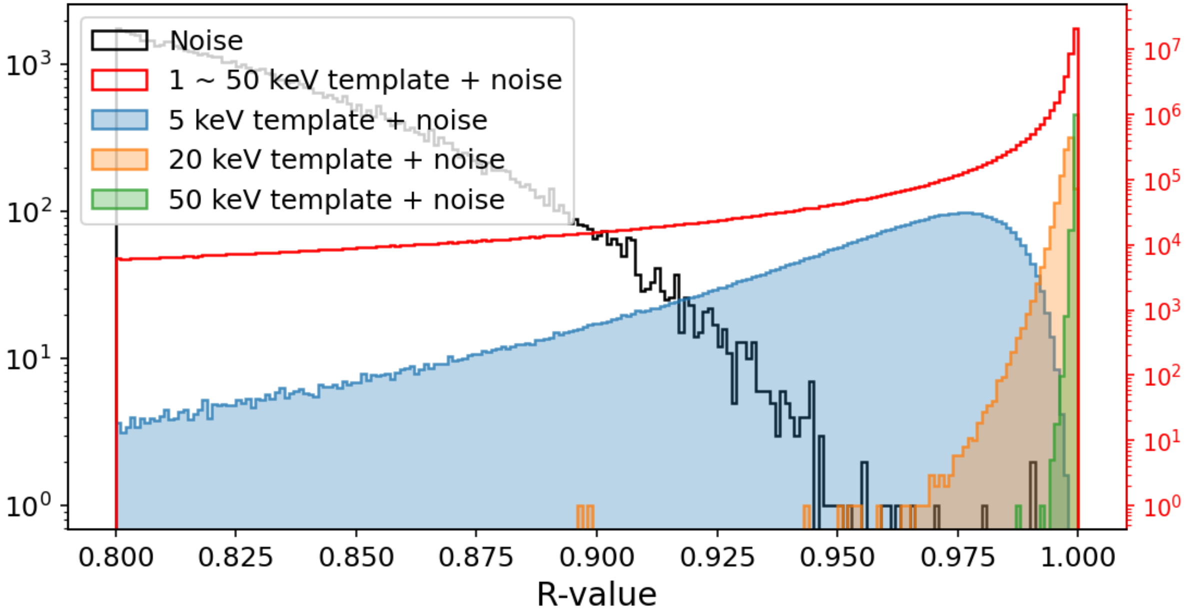
- **Use N data points with a single template to calculate the r-value**
- **Continuously calculate r-value; trigger and save signal at r-value local maximum**
- *Transfer function of 'Matched filter (optimal filter)'*

$$H(\omega_k) = h\frac{s^*(\omega_k)}{N(\omega_k)}e^{-j\omega_k i_M}$$

  - $N(\omega_k)$ *: noise power spectrum of detector*
  - $s(\omega_k)$ *: the Discrete Fourier Transform of signal shape*
  - i_M *: the maximum position of signal in the acquisition window*

Threshold determination & noise contribution

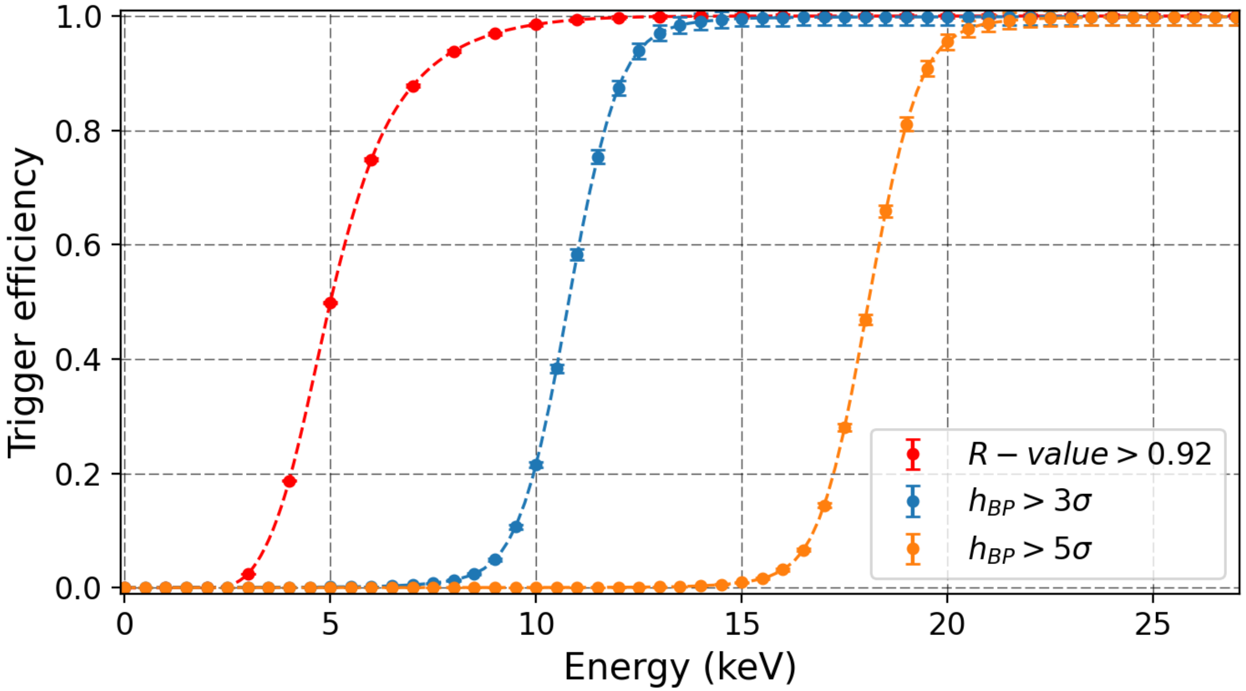


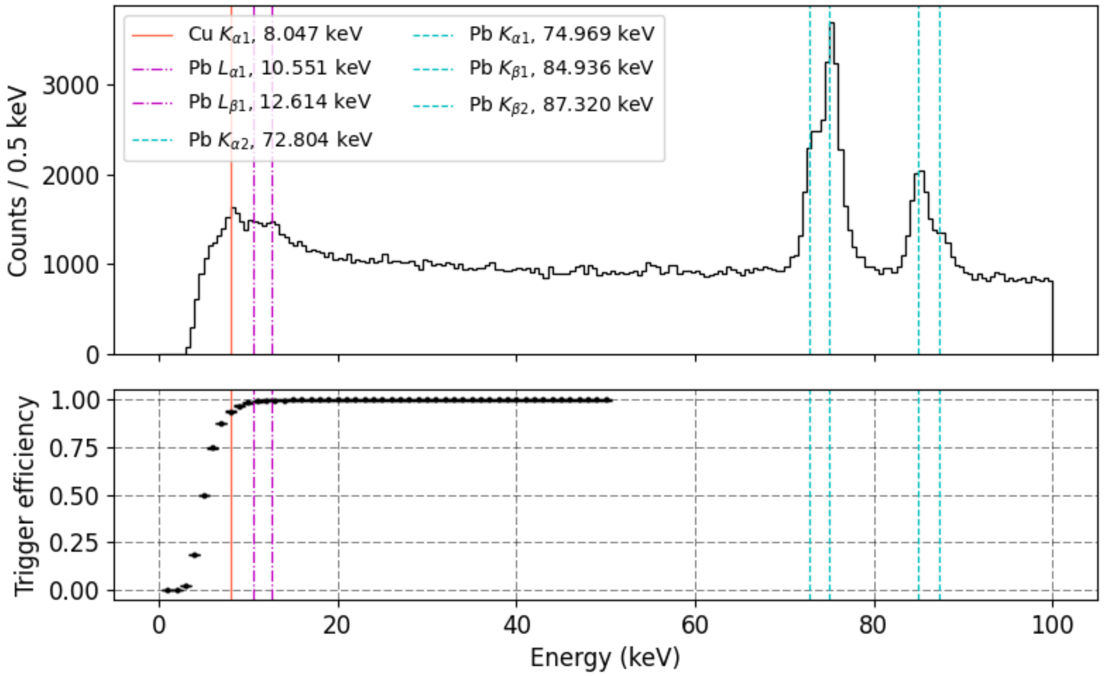


- Evaluation of trigger threshold, efficiency, and noise contribution
  - ~ 2.5 x 10^7 raw data samples (1-50 keV) analyzed
  - R-value calculated for :
    1. Noise data: random noise samples
    2. Simulated data: noise + signal template

- Consider noise contribution (Thr > R_{noise})
- Inefficiency of signal R-value.

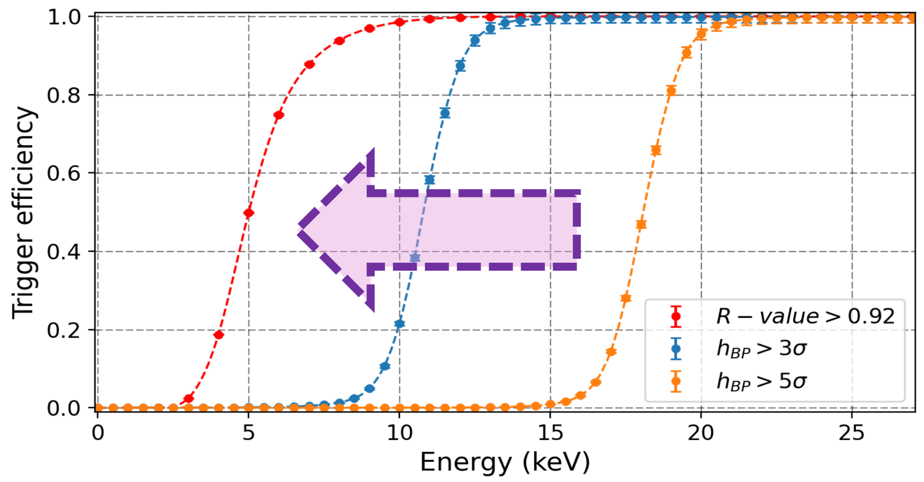
Performance

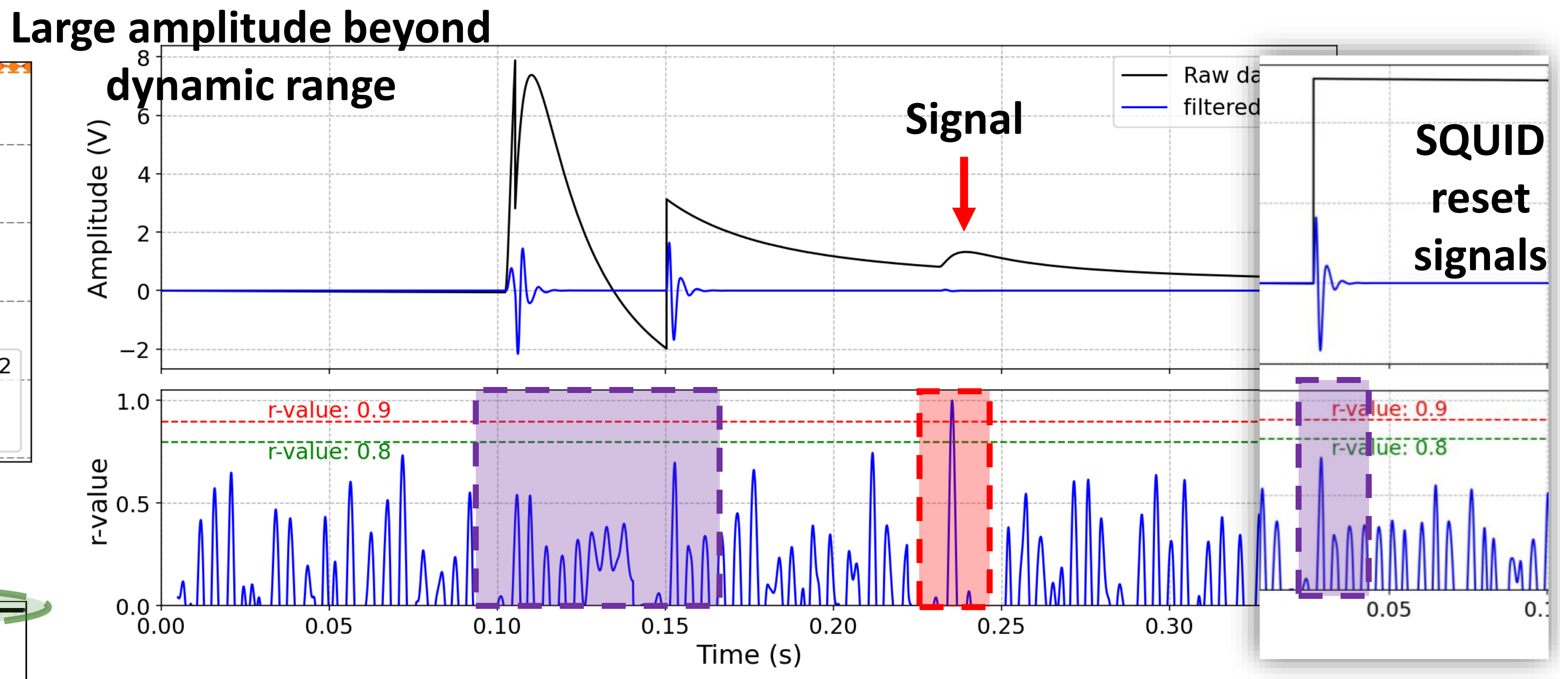


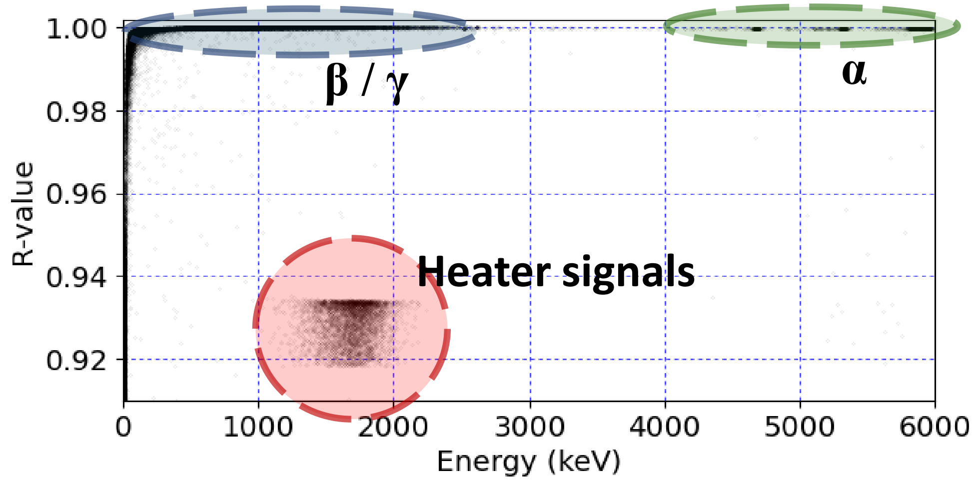


- Test of r-value trigger (bandpass filter) performance using the aboveground R&D experiment with Li_2MoO_4 crystal (mass: ~300g).
- The threshold of a conventional trigger was typically set to the noise RMS, corresponding to 3 or 5 σ.

Advantages

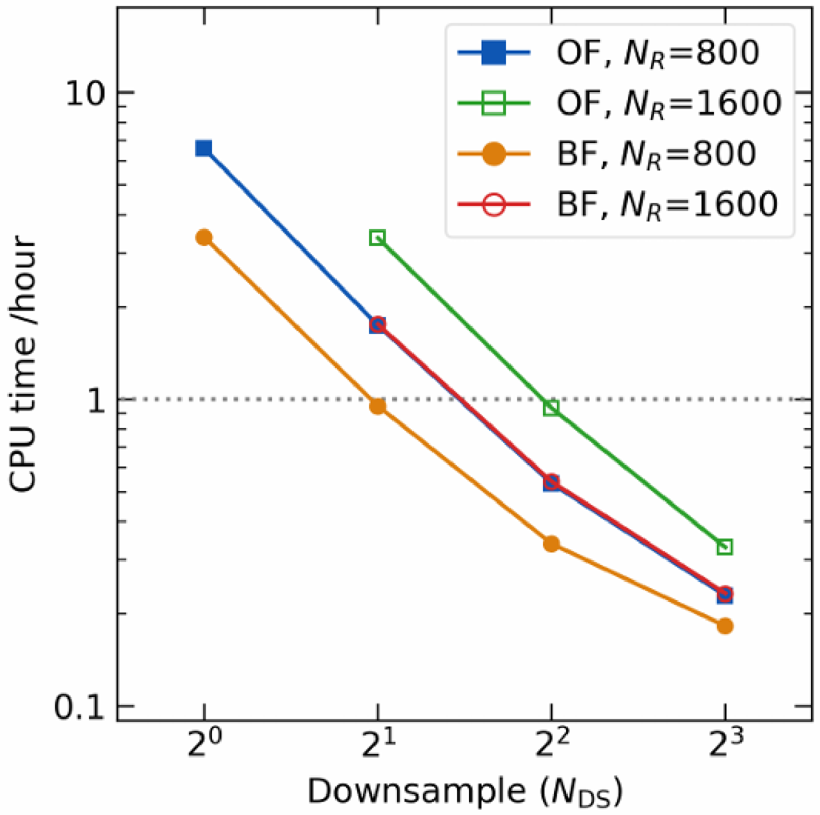






- Lower energy threshold than previous trigger.
- Can ignore unphysical events (SQUID reset signal, square wave, noise, etc.)

Consideration for practical use



CPU time for processing two hours' AMoRE-I continuous data for 8 heat channels from 1 AMOREADC module

- Real-time software trigger must be ensured for AMoRE-II.
- Each new data point requires:
  - Summation of N products, additional calculations, I/O, and filtering
- Optimal filter requires more computation than Butterworth bandpass filter.
- With sampling rate (100 kHz) and N ~ 1000 (10ms) → Real-time trigger is impossible.
- Solution → Apply Down-sampling
- A single-thread ROOT/C++ process can handle continuous data without delay at NDS ≥ 4 (25kHz)

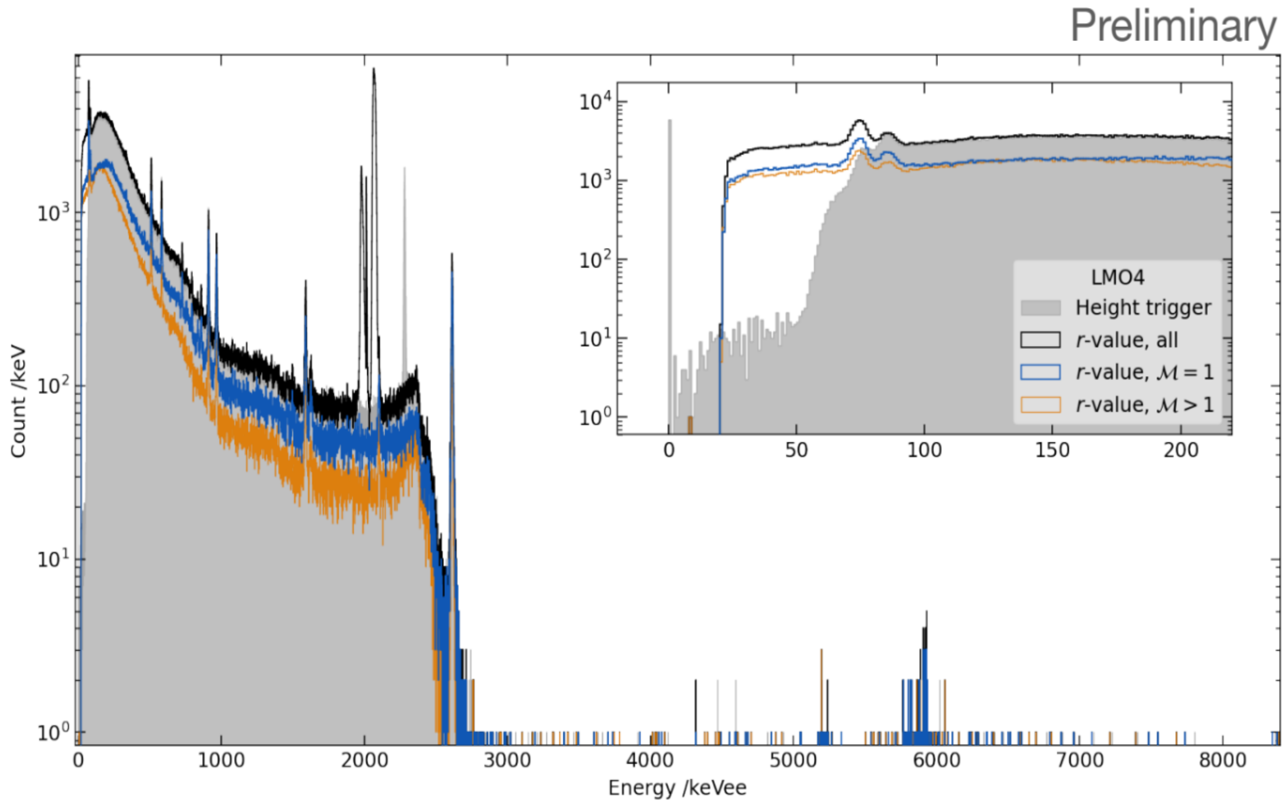
Apply to AMoRE experiment

- r-value trigger
  - signal template: 2.615 MeV γ signal obtained from calibration source data
  - Strongly dependent on the pulse shape, which changes with energy and event type (α, β/γ, heater signals, etc.).

- Reducing computing resource during the trigger process:
  - Down-sampling to reduce the number of data points.

- Suppress noise using simple filters such as Butterworth bandpass or optimal filters.

Apply to AMoRE experiment



- Energy spectrum of Source calibration data by $Li_2{}^{100}MoO_4$ crystal detector. (Crystal mass: ~ 300g)
- X-ray peaks from lead are clearly observed at 72.8, 74.9, and 84.9 keV. These peaks can be used for energy calibration in the low-energy range.
- Most of AMoRE-I detectors reach energy thresholds below 50 keV_{ee}.
  - the lowest energy threshold: < 10keV

Summary

- A new trigger logic based on the r-value is being developed.
  - Consider the optimized filtering:
    optimal filter, low-, high-, bandpass filter, …

- It achieves a lower energy threshold than the conventional pulse-height-based trigger.

- The new trigger has been tested with both R&D experimental data and AMoRE-I data.

- It will be applied to real-time data taking with down-sampling in the AMoRE-II experiment.