Lowering the energy thresholds for the CUORE experiment

A comparison between optimum trigger and derivative trigger performances in the search for $0\nu\beta\beta$

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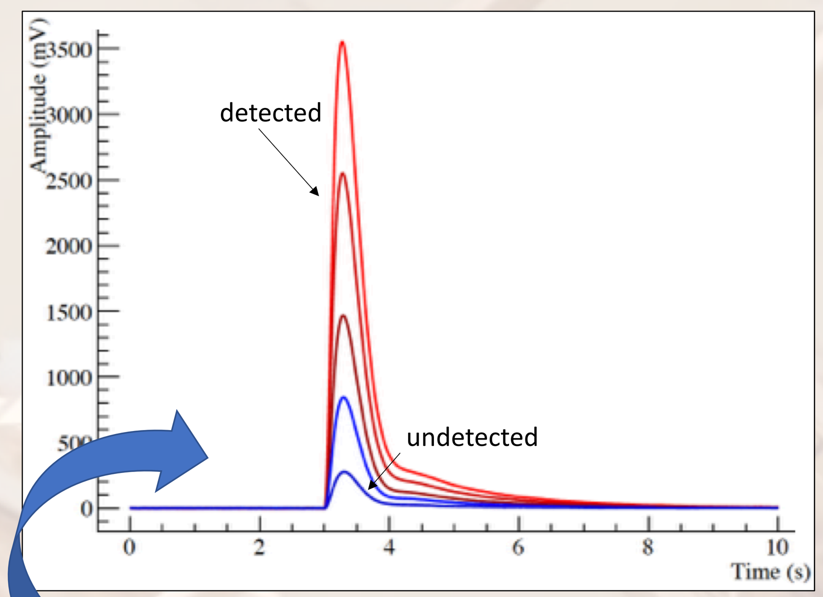
CUORE is a tonne-scale experiment located at the Laboratori Nazionali del Gran Sasso that exploits bolometric technique to search for neutrinoless double beta decay of ^{130}Te.
In this contribution we will present how the trigger algorithm affects both the interpretation of the energy spectrum and the sensitivity for low energy phenomena. In this respect, we will consider in particular the effects the trigger algorithm adopted has on the way coincident events among different crystals are identified.

Derivative vs Optimum Trigger

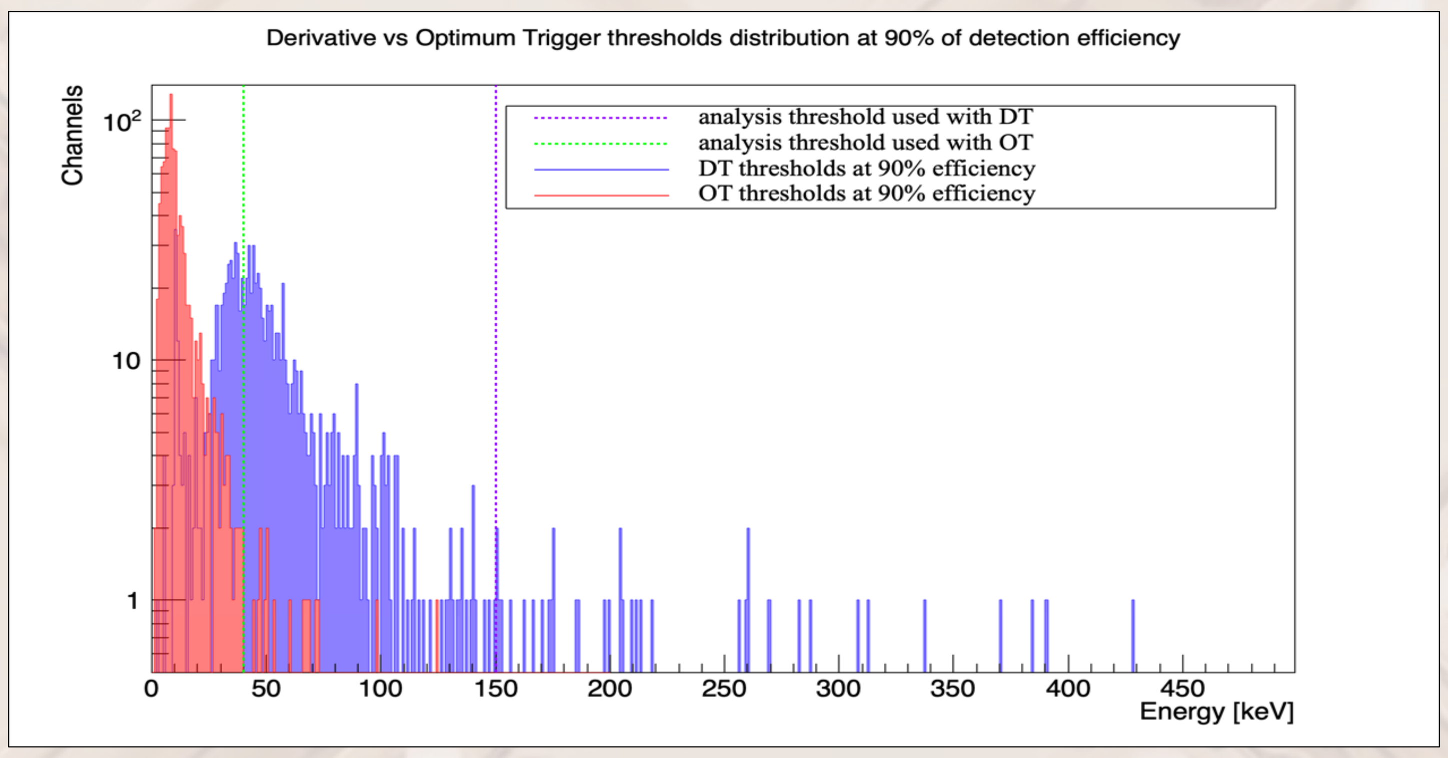


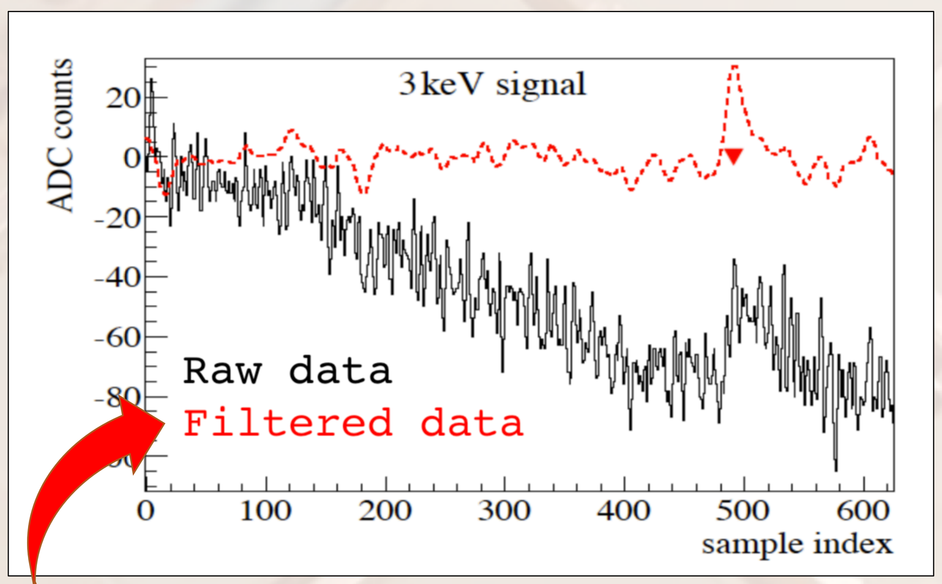
Derivative trigger algorithm:

- It works on the **derivative** of the **raw** waveform
- It acts on the rising edge of a pulse
- The threshold is based on the noise RMS of each bolometer

During the online data acquisition, we save continuous detector waveforms and separately trigger them with the derivative trigger (*DT*) technique: this is an elementary algorithm still suitable for the $0\nu\beta\beta$ decay search. We recently adapted the optimum trigger algorithm[1] (*OT*) to CUORE data and retriggered them with this technique. Signals are filtered with the optimal filter technique. In this way, trigger thresholds are strongly reduced thanks to the higher SNR.

To select physical events to include in the final specturm for the $0\nu\beta\beta$ decay search, we set a common analysis threshold to every bolometer in order to make sure we can detect signals irrespectively with all of them because their trigger threshold is below the fixed value. We decide it according to the trigger threshold distribution. We choose 150 keV and 40 keV for DT and OT analysis respectively.





Optimum trigger algorithm:

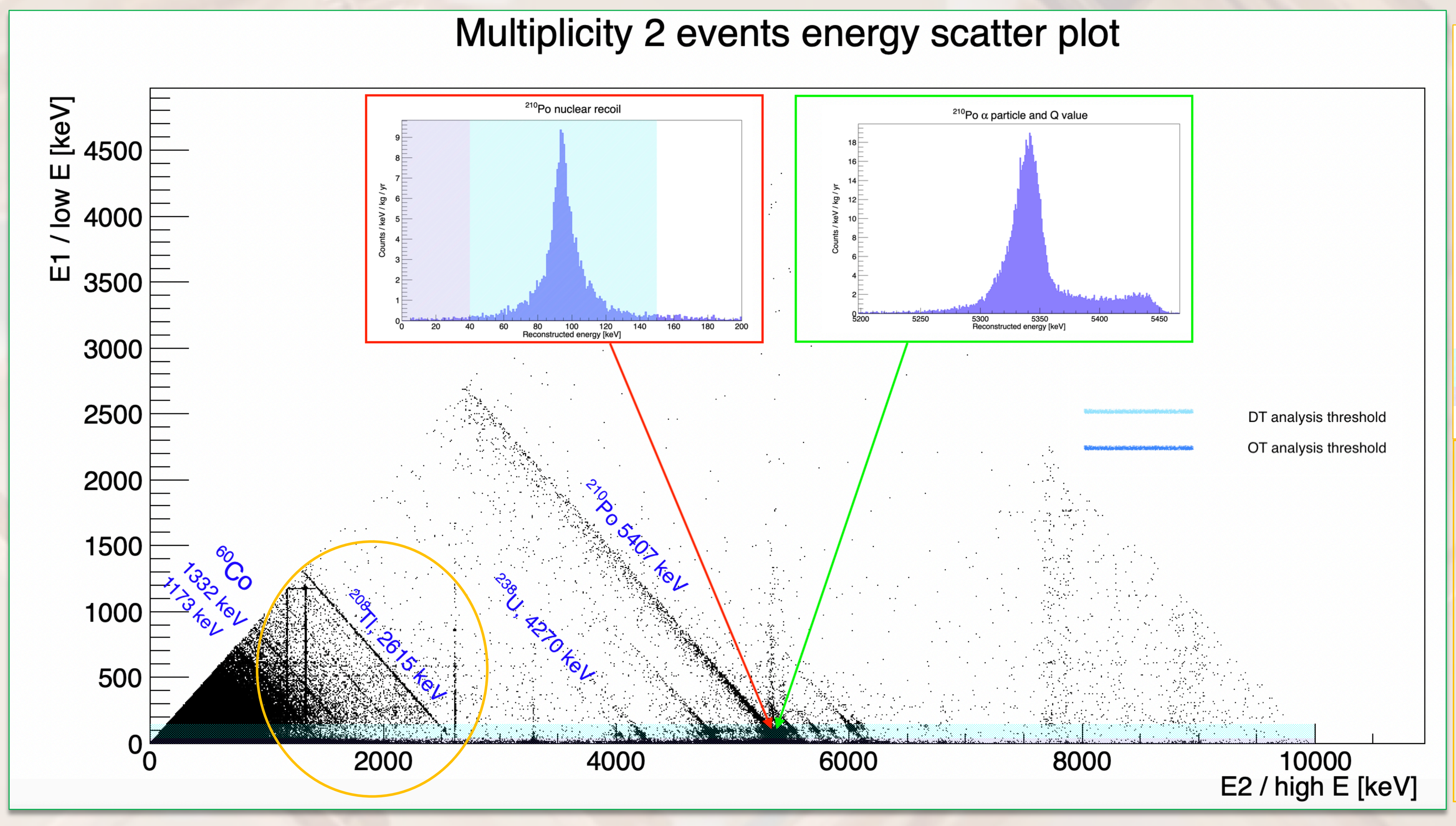
- It works on the **filtered** waveform
- Once the optimum filter transfer function is defined the baseline is filtered
- A trigger threshold, based on the filtered noise RMS, is applied

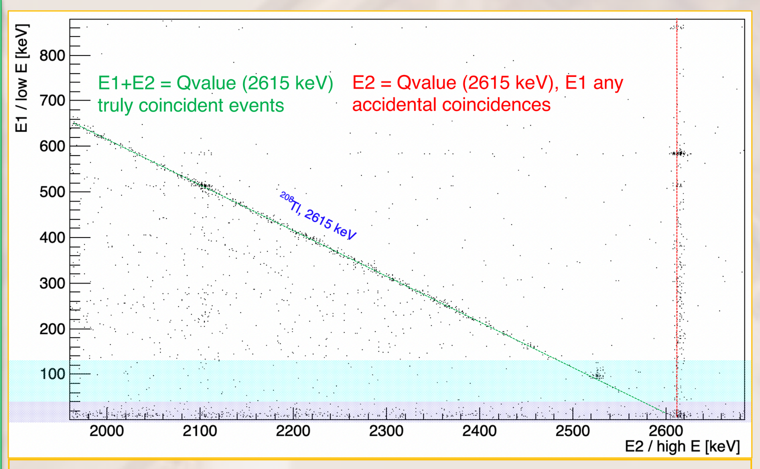
Analysis of the spectrum of particle interactions in multiple crystals

From MC simulations, we expect a $0\nu\beta\beta$ event to release the whole energy available in a single crystal in with ~88 % probability. For this reason, we include in the full analysis chain the assignment of a variable of multiplicity to physical interactions. Multiplicity corresponds to the number of bolometers involved in a particle process within a given (optimized) coincidence window.

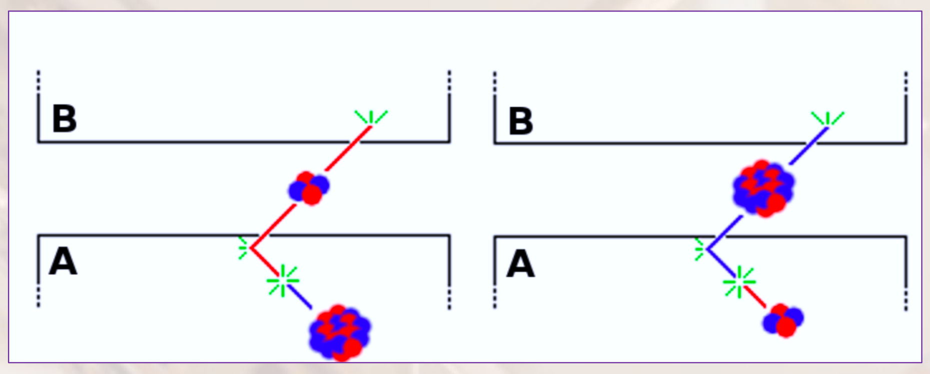
Lowering the trigger thresholds has an impact on the energy range of particle interactions we can explore. The ability to detect low energy events considerably increases our efficiency of reconstruction of events with energy release in more than one bolometer, that is to say multiplicity superior to 1.
Disentangling M_1 and $M_{x\geq2}$ (in particular M_2) interactions has benefits for our background model reconstruction. Alpha decays coming from structures in the neighbourhood of CUORE towers correspond to the biggest contamination for the experiment[2] and can be correctly quantified if both the α particle and the nuclear recoil are fully reconstructed as particle events.

We show the scatter plot of the energy distribution of multiplicity 2 events. In the M_2 events couple, X axis refers to high energy event, whereas Y axis represent the low one ($E_1 < E_2$ always). Derivative and optimum analysis thresholds are superimposed (150 and 40 keV, respectively). Nuclear recoil and α particle peaks from the the decay of a known contaminant (^{210}Po, Qvalue = 5407 keV)are also presented to highlight the effect on multiplicity 2 spectrum reconstruction.



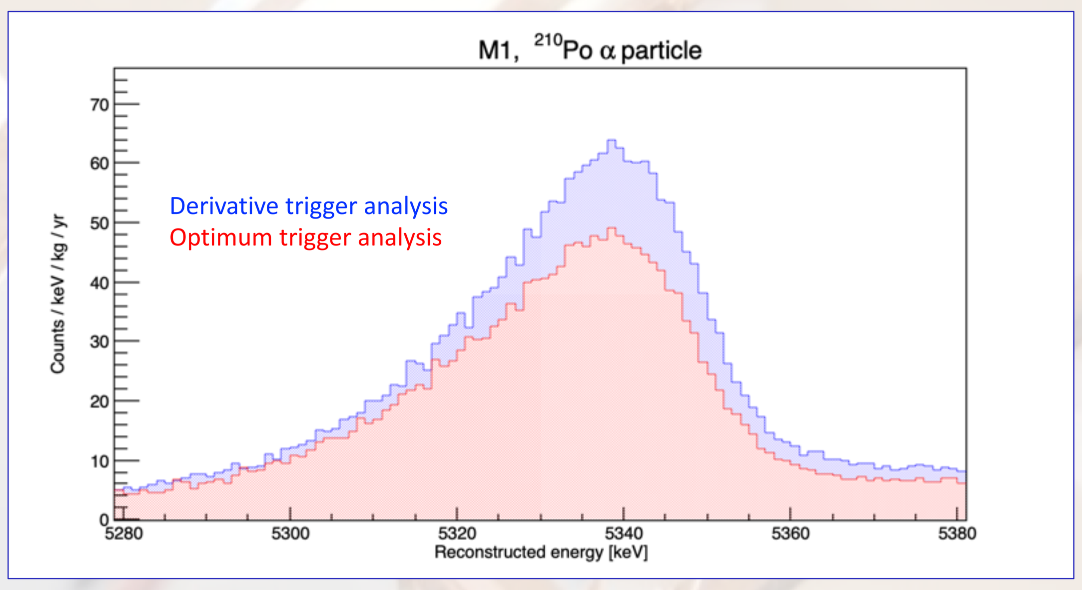


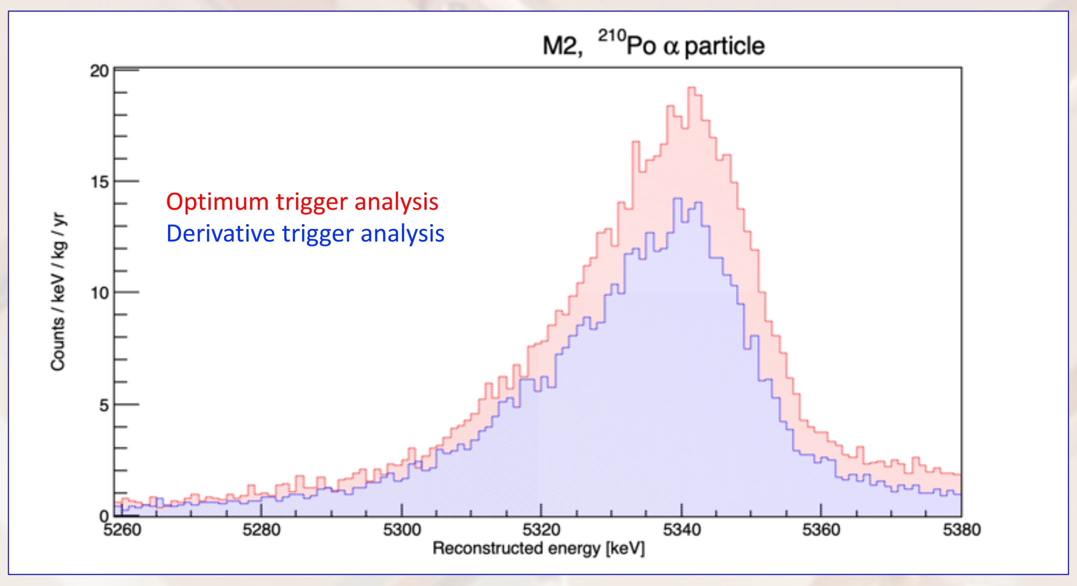
Lines with negative slope represent truly coincident particle events on two bolometers (E_1+E_2 = 2615 keV, namely the thallium photopeak), whereas vertical lines (E_2 = 2615 keV, E_1 any positive value) often correspond to accidental coincidences: by chance, uncorrelated interactions involve different crystals within the same time window. This also applies to other lines in the spectrum such as ^{210}Po α decay (5407 keV).



This is a schematic representation of the two processes populating the alpha and recoil peaks in multiplicity 2 spectrum. A and B are two CUORE bolometers.

As the old threshold (150 keV) completely excludes nuclear recoils from coincidences reconstruction, we will not consider this constrain in the analysis that follows: each bolometer will contrbibute with its own energy threshold as shown above. In order to show the improvement we obtain with optimum trigger, in particular in the capability to distinguish events in which all energy is released in a single crystal from those in which α and daughter nucleus end up in different bolometers, is also made clear showing that events in M_1 spectrum move to M_2 when moving from the derivative (*blue*) to optimum (*red*) trigger analysis. We consider the ^{210}Po α particle and compare M_1 and M_2 spectra. To exclude accidentals, we apply a cut on the total energy ($E_1 + E_2$ = Qvalue) of M_2 spectrum.





In conclusion, it must be highlighted that the analysis presented here is preliminary and highlights only a small part of the improvements optimum trigger can produce in CUORE analysis.

Besides representing a powerful tool to updgrade our background model, optimum trigger can help us improve neutrinoless double beta decay search, e.g. by considering also the situation in which the electrons emitted release energy in multiple crystals.

Low energy studies, such as dark matter and solar axions search[1], also take advantage from lowering the energy thresholds.

1. C. Alduino *et al.* (CUORE Collaboration). Low energy analysis techniques for CUORE. *European Physical Journal C* ***77****, 12 (2017).*
2. C. Alduino *et al.* (CUORE Collaboration). The projected background for the CUORE experiment. *European Physical Journal C* **77**, 543 (2017).