Ongoing studies on notch software filters for the CUORE experiment

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CUORE and the bolometric technique

CUORE is a ton-scale underground bolometer array of 988 TeO_2 cubic crystals operated at the INFN Gran Sasso National Laboratories (LNGS) with the main aim of searching for the neutrinoless double beta decay (DBD) of ^{130}Te and other rare processes[1]. The crystals are arranged in 19 towers placed in a custom built dilution refrigerator able to cool down and keep the detector at the stable temperature of ~ 10 mK.

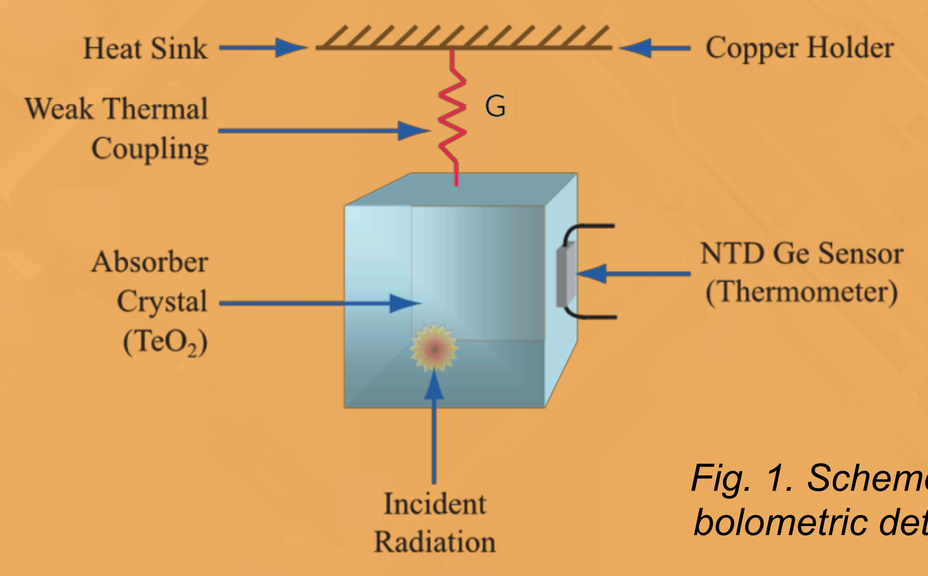

Fig. 1. Scheme of a bolometric detector

The energy released by particle interactions in the crystal cause a temperature rise. Neutron Transmutation Doped Ge thermistors transform the temperature pulses induced by particles into voltage pulses. They are biased with a constant current and their voltage is low-pass filtered, amplified and continuously digitized at a sampling frequency fs = 1 kHz.

$$\Delta T = \frac{\Delta E}{C(T)} \sim 100 \frac{\mu\mathrm{K}}{\mathrm{MeV}} @ 10\mathrm{mK} \quad C \propto T^3$$

The CUORE cryostat

The CUORE cryostat is made of 6 nested copper vessels thermalized at decreasing temperatures. The cooling power is provided by a dilution unit and 5 Pulse Tube (PT) Cryocoolers:

- custom adapted PT415-RM (Cryomech)
- cooling power: 1.2 W @ 4.2 K and 32 W @ 45 K for each PT
- 0.7 Hz rotating valve alternatively connects high/low pressure sides of a compressor to expansion volume

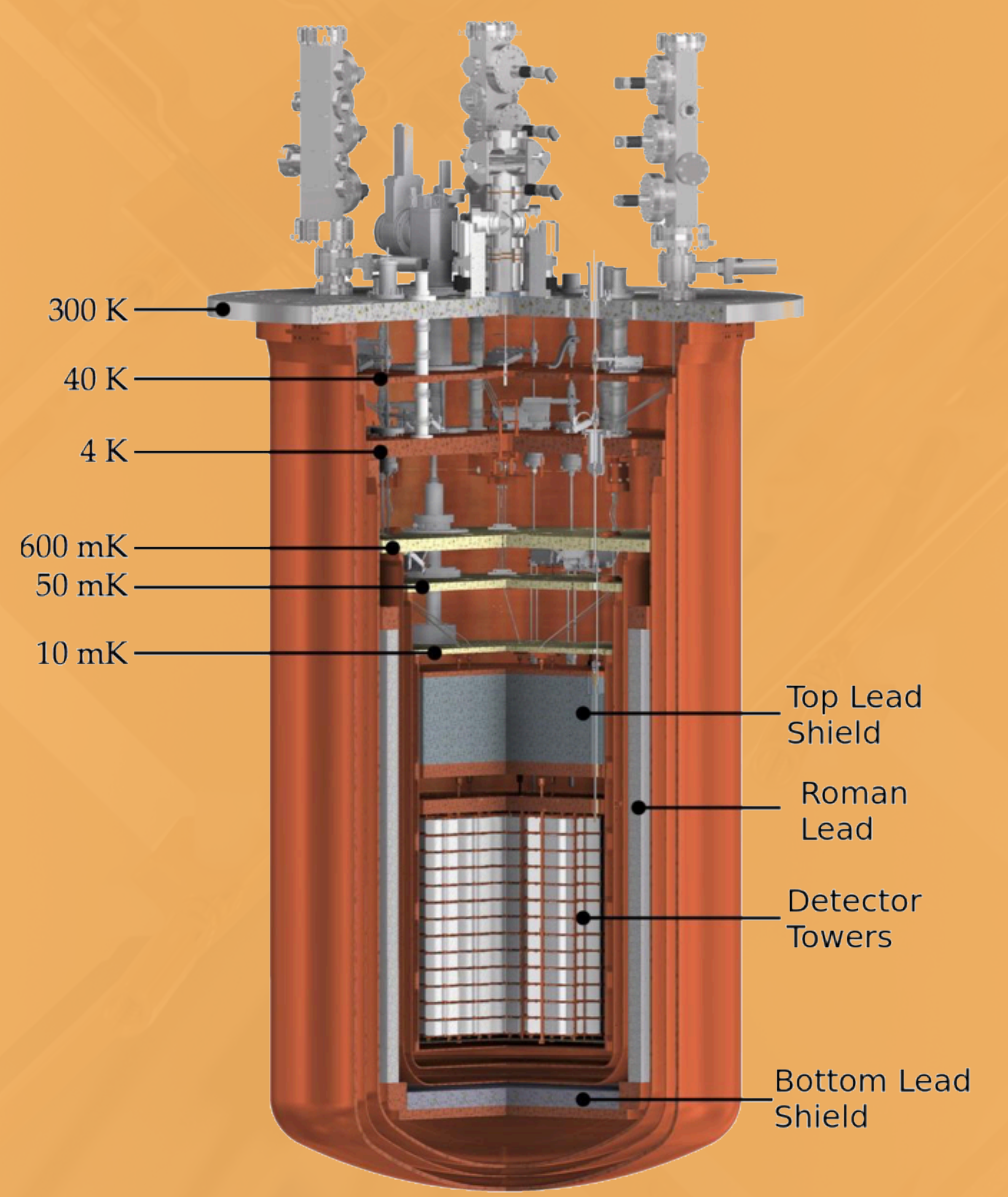

Fig. 2. The CUORE cryostat

Pulse Tube Cryocoolers

Pros:

- no moving part at low temperature reduce maintenance
- less transmitted vibrations compared to other mechanical cryocoolers
- no need for cryogen refills
- possibility to tune the relative phase of different rotary valves to reduce noise[2]

Cons:

- source of 1.4 Hz (and higher harmonics) vibrational noise

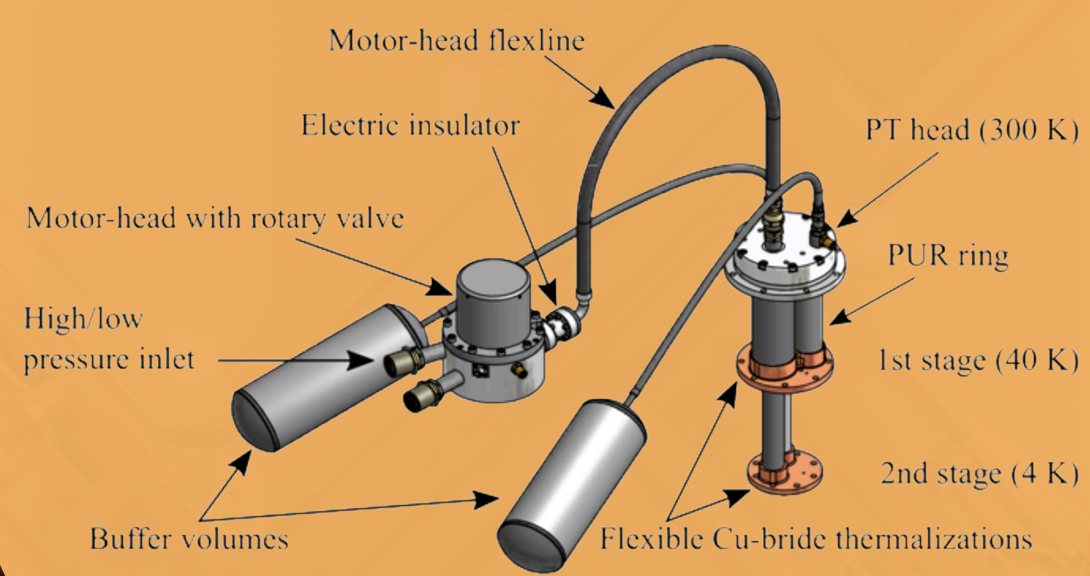

Fig. 3. The CUORE Pulse Tube Cryocoolers

Noise power spectra

The CUORE data analysis relies on 10 s waveforms around each trigger position[3]. Each waveform is processed with an Optimum Filter[5] to optimize the amplitude evaluation, hence the energy resolution[4].

The length W of the waveforms limits the resolution of the Discrete Fourier Transform (DFT) to $\Delta f = 1/W \sim 0.1$ Hz.

A sample of noise events with a 100 s window were used to investigate sub-structures of the Noise Power Spectrum (NPS, Fig. 4).

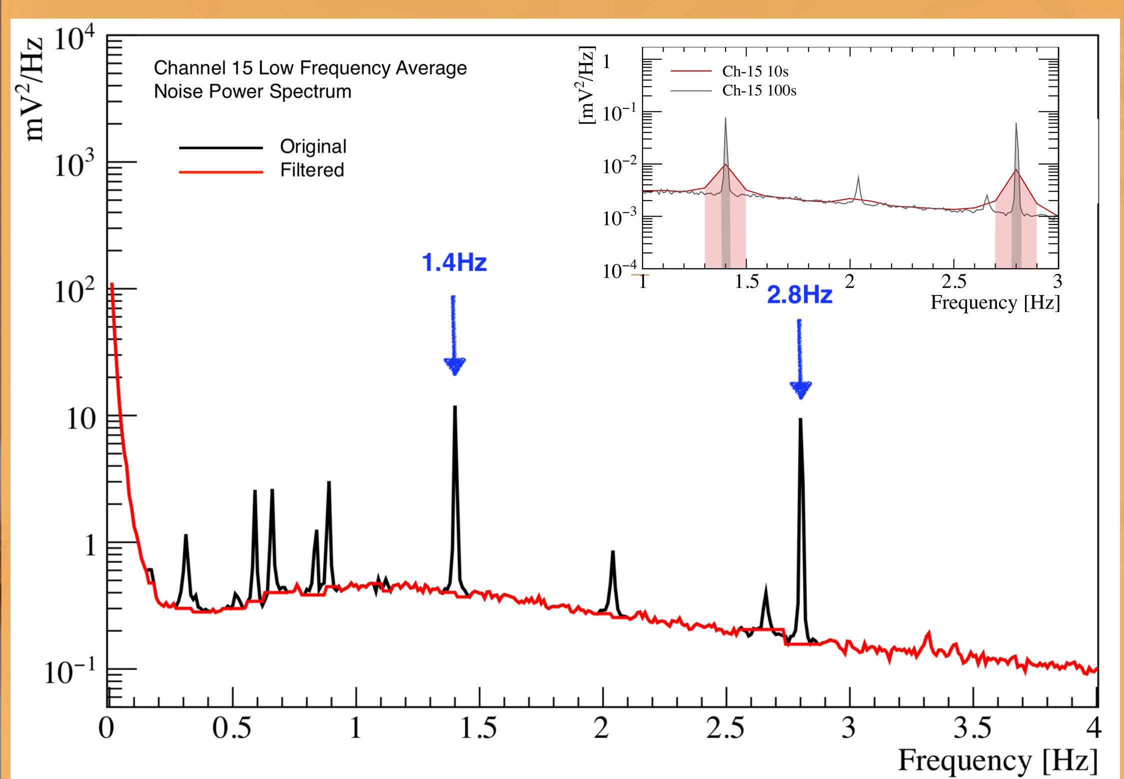

Fig. 4. A low frequency noise power spectrum

The expected average improvement in the noise resolution was estimated smoothing the peaks in the noise power spectrum aligning them to the continuum (Fig. 4):

$$1 - \langle \sigma_{smooth}/\sigma \rangle \sim 18\,\%$$

IIR Notch Filter

We are interested in removing the low frequency components, because there our signal lies: $0 < f < 5$ Hz. We would like to achieve:

- very precise removal of noise peaks in order to minimize the loss of signal components
- accurate estimation of the bandwidth and frequency of each noise source
- minimal deformation of the original pulse

We implemented a time domain notch filter:

$$y[n] = \sum_{i=1}^{2} a_i y[n-i] + \sum_{i=0}^{2} b_i x[n-i]$$

where $y[n]$ is the n-th sample of the filtered output signal, $x[n]$ is the corresponding sample of the input signal, a_i and b_i are constant coefficients that define the filter response.

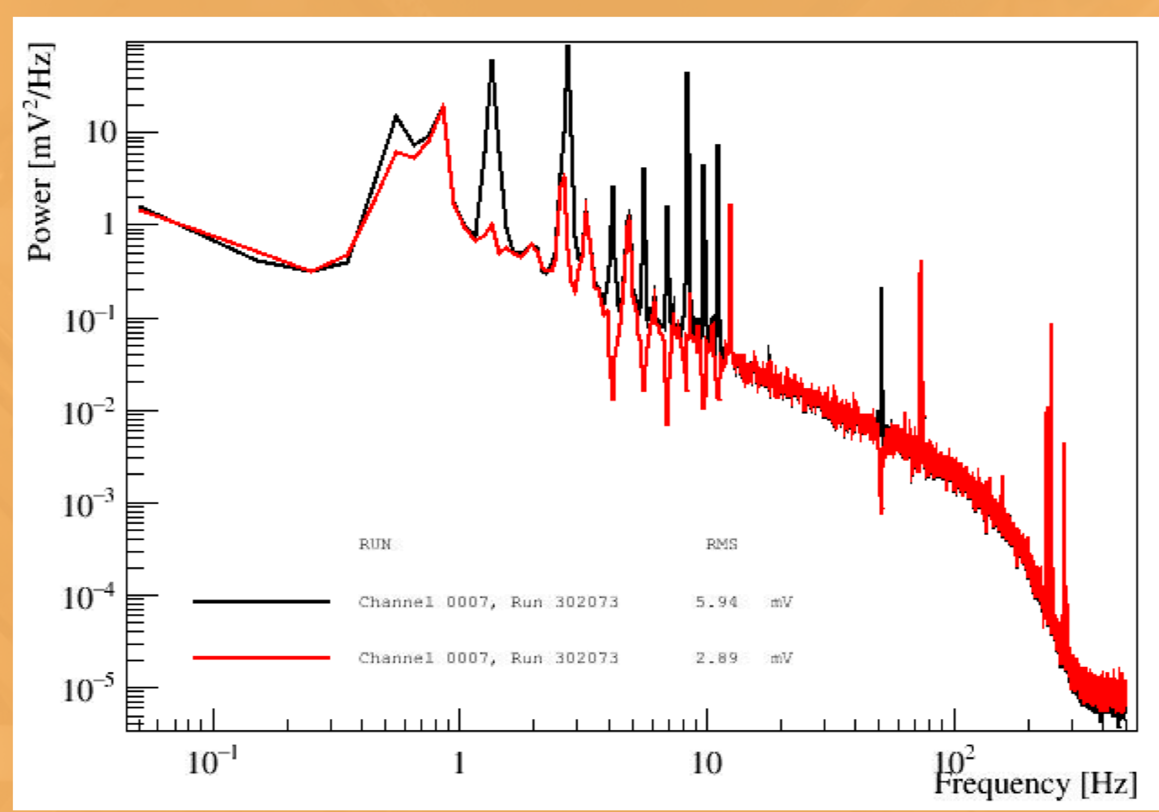

Fig. 5. Original (black) and filtered (red) noise power spectrum, 10 s window.

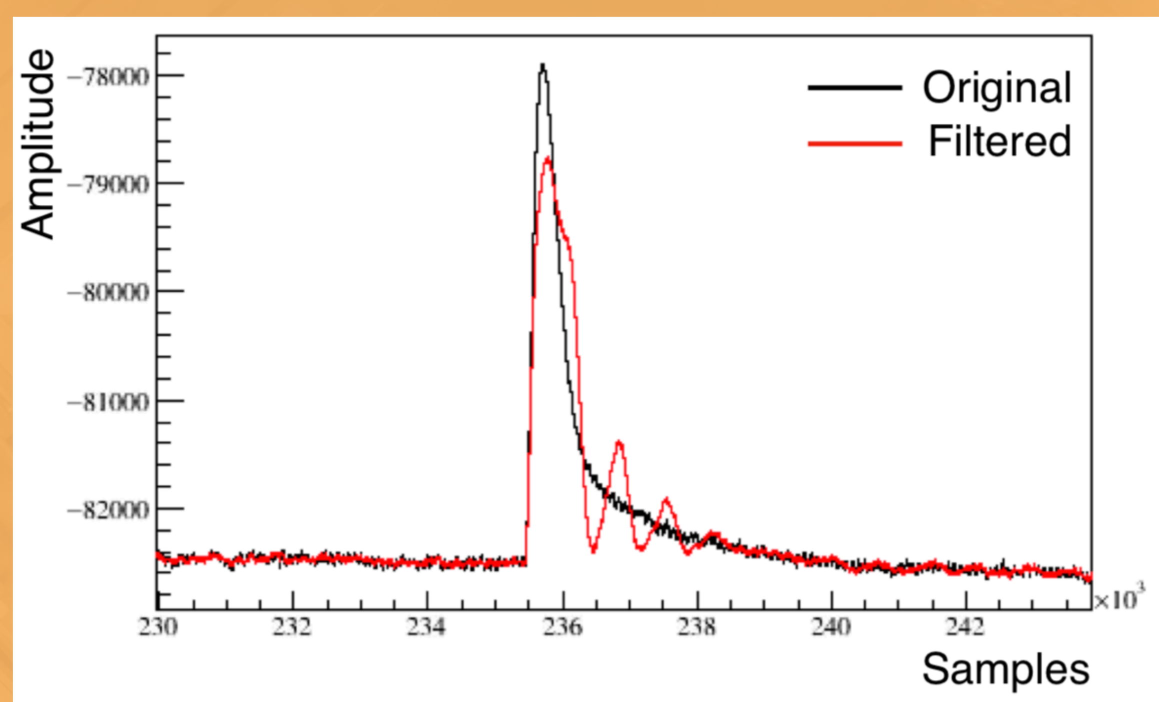

Fig. 6. Original (black) and filtered (red) CUORE pulse

Status and prospects

- Tests were performed on both acquired and simulated waveforms
- The notch filter is effective just on noise events, despite a transient response that grows as the inverse of the removed bandwidth
- When applied to thermal pulses, ringing is observed and the filtered pulse is distorted
- Work is in progress to reduce the duration of the transient response and the ringing

References:

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