Understanding the contributions to the CUORE background

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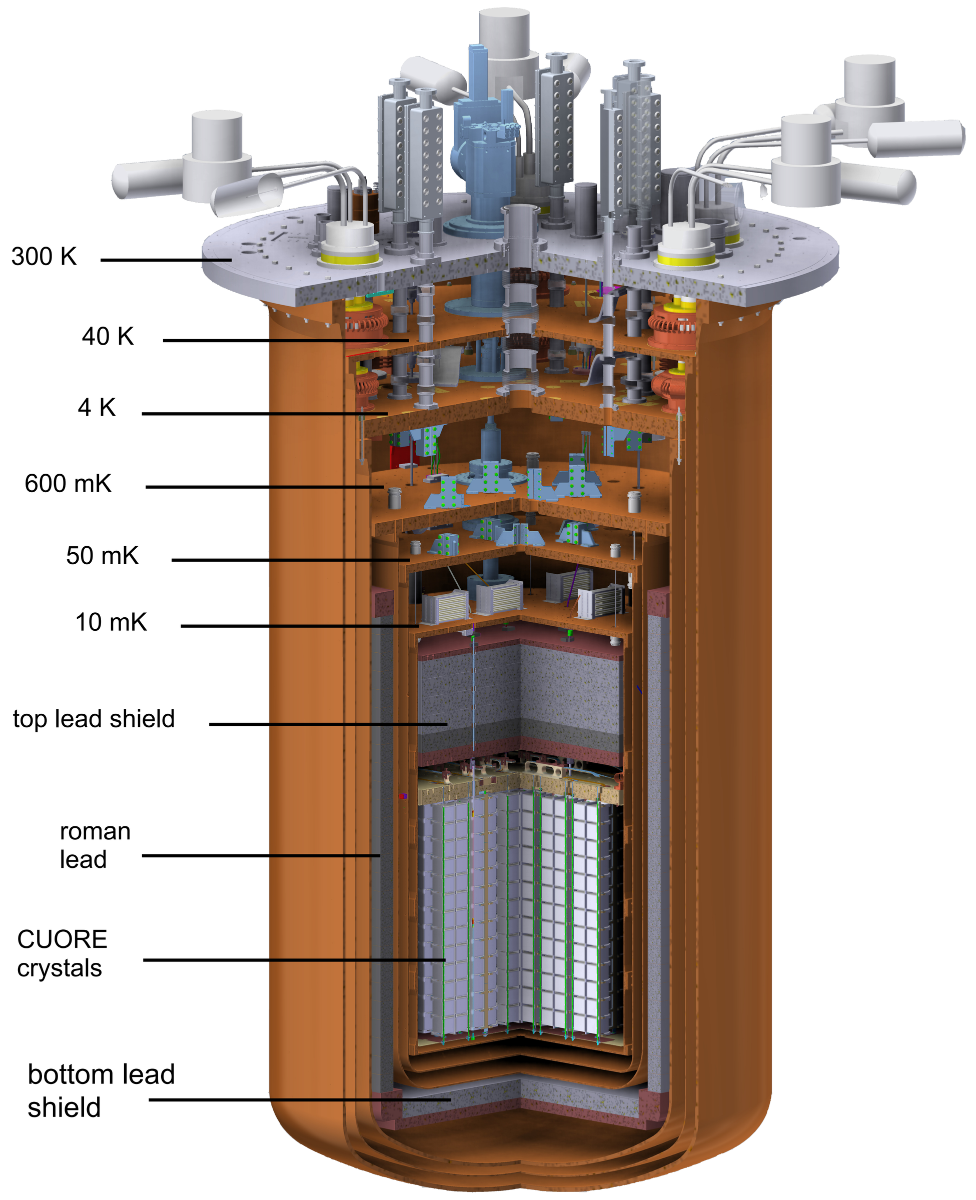
References:
[1] D. Q. Adams et al.,Phys. Rev. Lett. **124**, 122501 (2020)
[2] C. Alduino et al., Eur. Phys. J. C (2017) 77:543
[3] D. Q. Adams et al., Proceedings of Neutrino 2018 Conference, arXiv:1808.10342
[4] S. Pozzi, *Search for double-beta decay in ^{130}Te to the excited states of ^{130}Xe in CUORE-0*, PhD Thesis (2017)

1. The CUORE detector

- CUORE (Cryogenic Underground Observatory for Rare Events): 1-ton scale array of bolometric detectors aimed at search for $0\nu\beta\beta$ decay in ^{130}Te
- Located underground at Gran Sasso National Laboratories (LNGS), in Italy
- 988 pure TeO_2 crystals operated as calorimeters at 10 mK
- Ultra-low background: $(1.38 \pm 0.07)\cdot 10^{-2}$ counts/(keV·kg·yr) in the region of interest [1]
- CUORE cryostat comprised of six copper shields, each thermalized at different temperatures. Lead shields are also thermalized and protect the bolometers from external radioactivity
- Cool down thanks to 5 pulse tubes (~4 K) and a DU (dilution unit) refrigerator (base temp.)



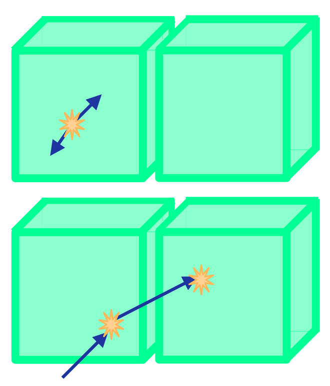
2. CUORE background model

In order to identify and evaluate the physics signatures contributing to the observed CUORE spectrum, the expected background is extracted by means of a detailed Monte Carlo simulation. This takes into account:

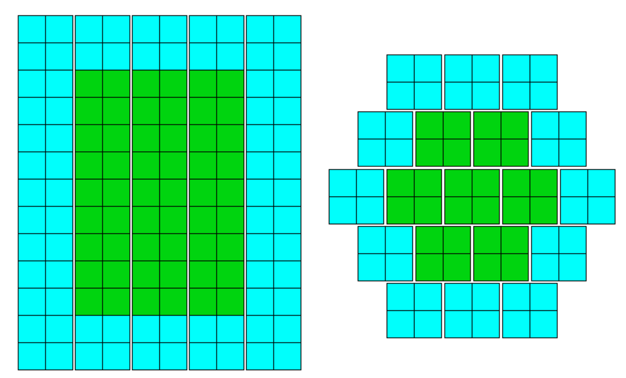
- The geometry of the experimental setup
- The background processes ($2\nu\beta\beta$ by ^{130}Te), the radioactive sources and their location in the detector
- The radiation interactions with the various parts of the detector
- The detector response and instrumental effects (thresholds, resolutions, etc.)

Thanks to the granularity of the CUORE detector, the number of crystals involved in an interaction (multiplicity) can be identified, and information on the positions of background sources in the detector are extracted. Moreover, an inner and an outer layer are distinguished, the former exploiting the shielding effect of the latter.

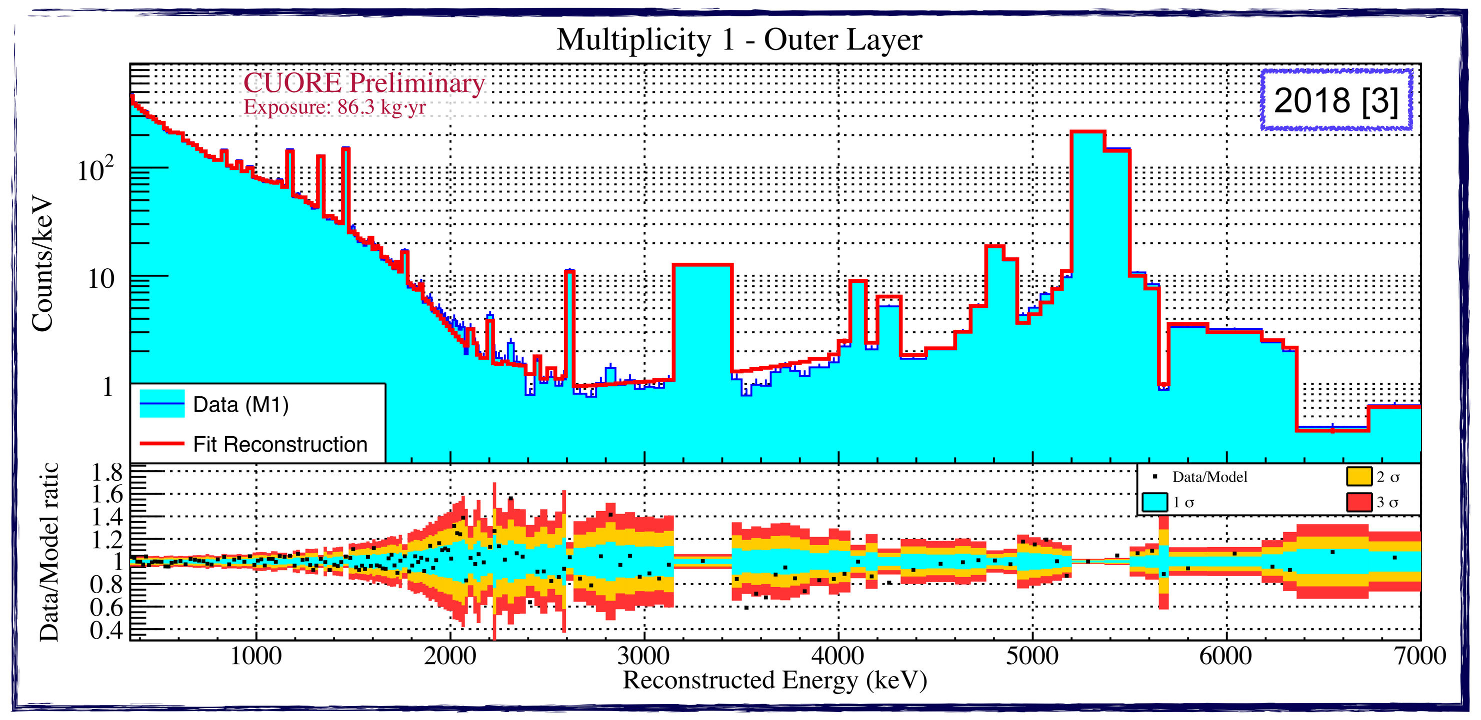
Events multiplicity



Inner (L0) and outer (L1) layer



60 background sources are simulated and a Bayesian MCMC fit with flat priors (except muons) is performed on the data:



3. The radioactive sources: the alpha region

To accomplish the goal of ultra-low background, extremely accurate procedures to avoid contamination were applied during the construction of CUORE. Despite this, some background sources from contamination of the crystal themselves, and the copper shields are visible in the CUORE spectrum [2]:

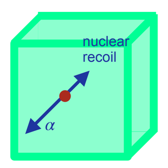
- ^{40}K (environment)
- ^{60}Co (Cu cosmogenic activation)
- ^{210}Po, ^{108m}Ag, ^{202}Pb, ^{207}Bi
- ^{232}Th chain nuclei
- ^{238}U chain nuclei
- ^{190}Pt (crystal bulk)

→ γ **lines**

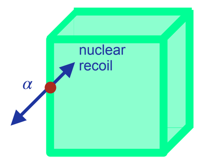
→ α **lines:** a preliminary study of the alpha region of the CUORE spectrum is shown in this work

A deep understanding of such contaminants is necessary to further improve the background model

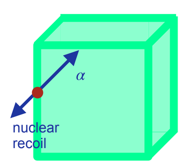
α decay: $E_{tot} = E(\alpha) + E(\text{nuclear recoil})$ → Depending on the contamination position on the crystal, different signatures are distinguished:



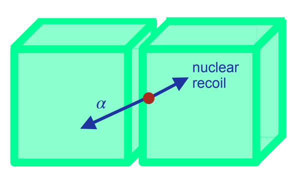
Bulk contaminant
M1, $E_{meas} = E_{tot}$



Surface contaminant
M1, $E_{meas} = E(\text{recoil})$



Surface contaminant
M1, $E_{meas} = E(\alpha)$

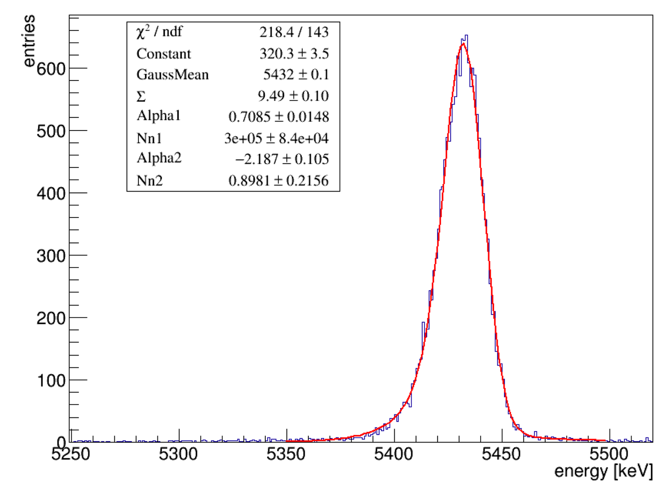


Surface contaminant
M2 single energy: $E^{(1)}_{meas} = E(\alpha)$, $E^{(2)}_{meas} = E(\text{recoil})$
M2 total energy: $E_{meas} = E_{tot}$

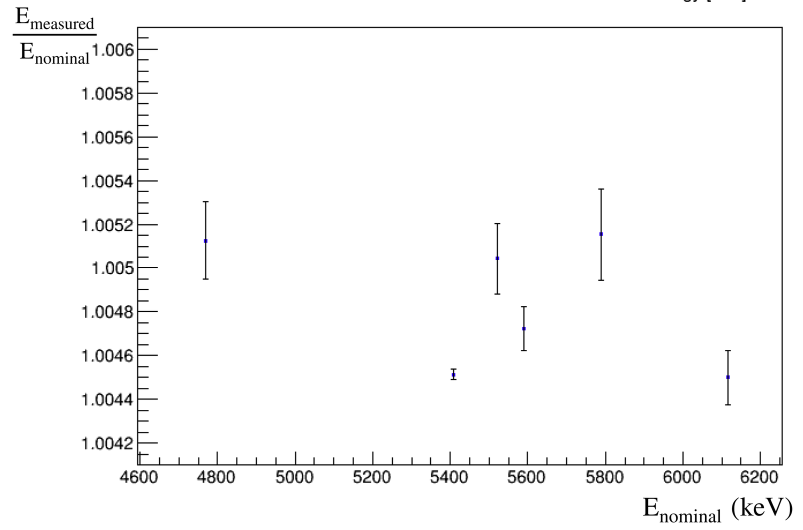
4. Alpha lines position in energy

Study of surface contaminations by observing M2 total energy spectrum:

- Used peaks (decay's Q_{value}): ^{230}Th, ^{210}Po, ^{228}Th, ^{222}Rn, ^{224}Ra, ^{218}Po
- Fit function: double crystal ball
- A systematic shift of 25-30 keV towards higher energies with respect to the nominal values is observed:



Element	*Nominal energy (keV)*	*Measured Energy (keV)*
^{230}Th	4770.0	4794.45 ± 0.84
^{210}Po	5407.5	5431.87 ± 0.12
^{228}Th	5520.1	5547.96 ± 0.89
^{222}Rn	5590.3	5616.71 ± 0.56
^{224}Ra	5788.9	5818.7 ± 1.2
^{218}Po	6114.7	6142.19 ± 0.76



QUENCHING FACTOR (q): an α particle interacting with TeO_2 crystals generates a signal higher than expected

$$\frac{E_{ee}}{E_{nominal}} \equiv q$$

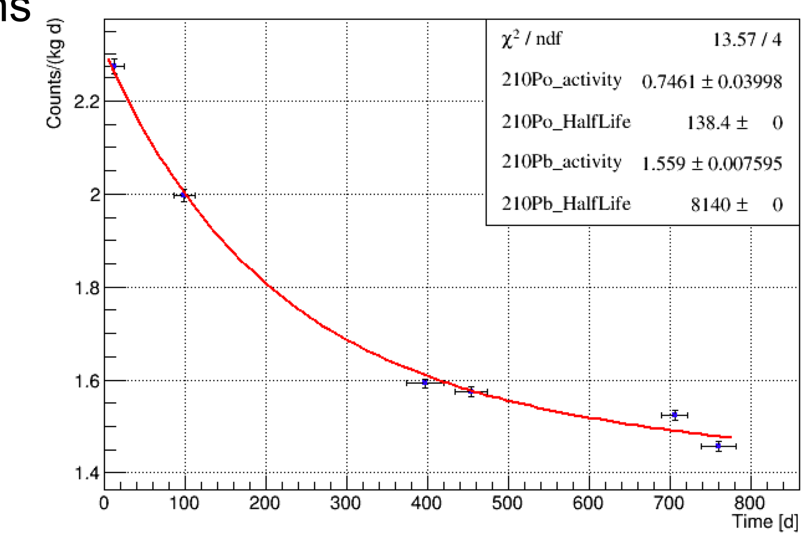
→ CUORE-0 [4] : q = 1.007
CUORE: study ongoing to determine q more precisely

5. Rate vs time: secular equilibrium study

The time dependence of the visible alpha lines at $E(\alpha)$ from the ^{238}U chain is evaluated over a period of Δt = 2 years:

- ^{238}U, ^{230}Th: $T_{1/2} >> \Delta t$, constant rate is expected
- ^{218}Po: $T_{1/2} << \Delta t$, constant rate is expected, equal to parent decay rate if secular equilibrium occurs
- ^{210}Po + ^{210}Pb: fit with 2 exponentials on the ^{210}Po alpha peak to determine the two contributions

Element	*Activity (10^{-2} counts/kg/day)*
^{238}U	1.72 ± 0.08
^{230}Th	1.31 ± 0.08
^{218}Po	1.48 ± 0.05
^{210}Pb	155.9 ± 0.8
^{210}Po	74.6 ± 3.9



- ^{230}Th activity is slightly lower than ^{238}U: this hints for a possible breaking point of the chain.
- ^{230}Th, ^{218}Po activities are very similar, indicating secular equilibrium is likely.
- ^{210}Pb and ^{210}Po represent two breaking points of the chain.