Recent Progress on BSM and Dark Matter Searches in CUORE

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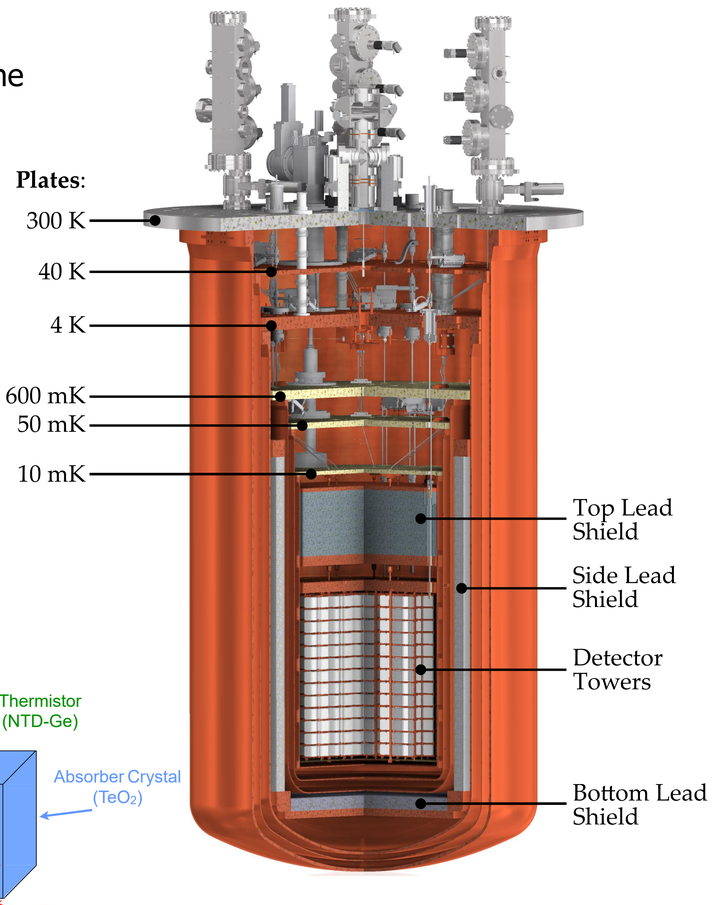
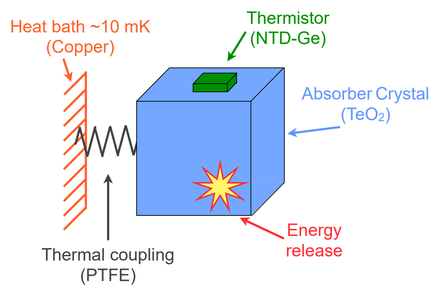
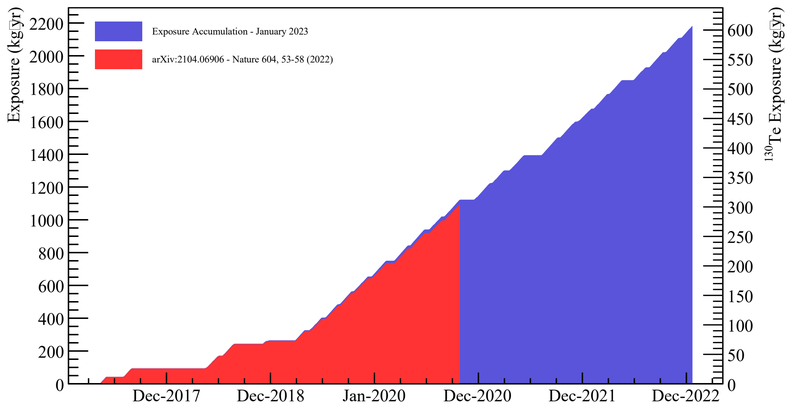
CUORE

The Cryogenic Underground Observatory for Rare Events is a tonne scale array of 988 TeO_2 bolometric crystals housed at INFN Gran Sasso National Laboratories (LNGS) with 3600 m.w.e. overburden. The main goal is to detect the neutrinoless double beta decay of ^{130}Te at its Q-value of 2527 keV. Energy deposition within the crystal is detected by a Neutron Transmutation Doped (NTD) Ge sensor glued to each crystal. The array is housed within a pulse tube (PT) cryostat that reaches 10 mK through the dilution refrigeration process. CUORE has a target energy resolution of ~5 keV.



$$\Delta T = \frac{\Delta E}{C(T)}$$
$$C(T) \propto T^3$$





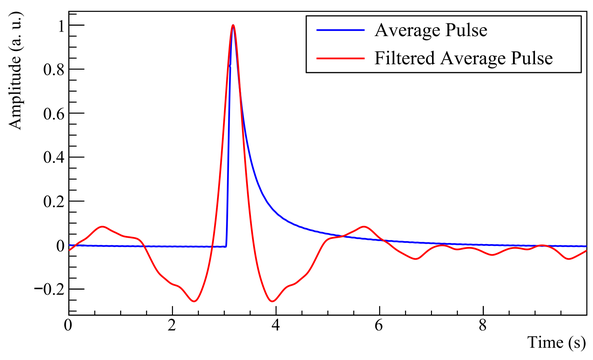
CUORE has been operating since 2017 and has collected over 2 $T \cdot yr$ of exposure. With the large amount of data, cryogenic environment, and shielding, CUORE can be sensitive to dark matter signals in the region below 100 keV.

Filtering Technique

The Optimum Filter (OF) leaves the amplitude of an event the same while suppressing the noise from the filtered pulse shape.

Optimum Filter transform function:

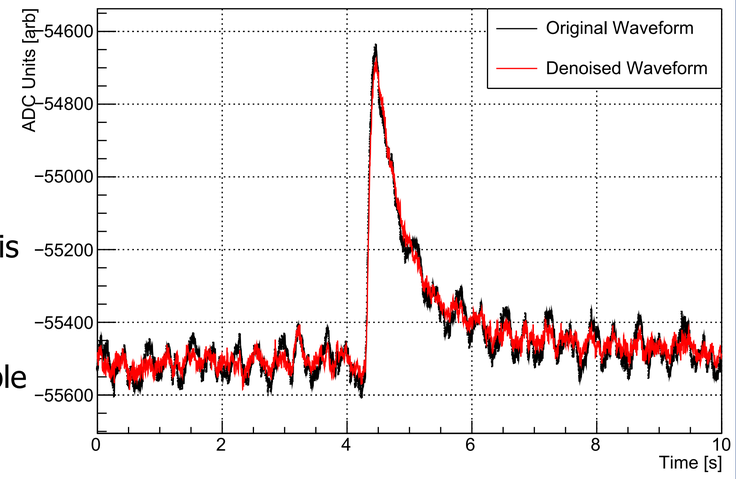
$$H(\omega_k) = h\frac{s^*(\omega_k)}{N(\omega_k)}e^{j\omega_k t_m}$$



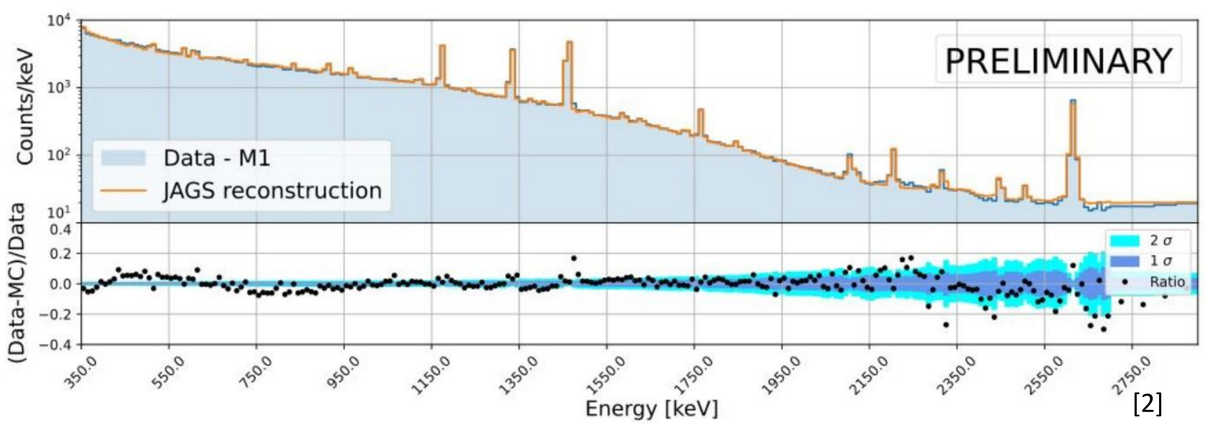
Data Processing

Denoising techniques developed using accelerometers and microphones around the CUORE cryostat can be applied to our data for a cleaner energy spectrum. This benefits low energy waveforms by reducing acoustic and oscillatory noise, particularly from the PT, that is apparent on smaller amplitude events.

The background model is very reliable at energies > 300 keV and is constantly improving. There are ongoing studies for improving accuracy at lower energies, which will benefit dark matter searches.



[1]

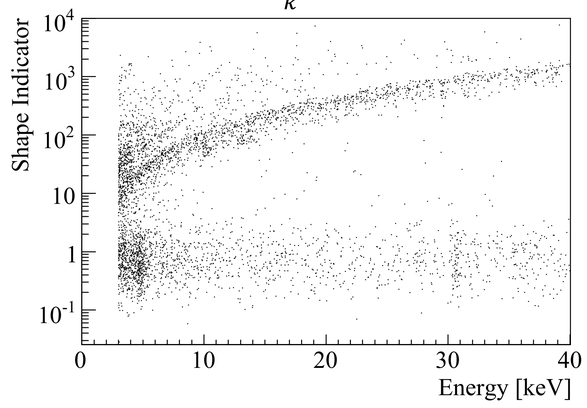


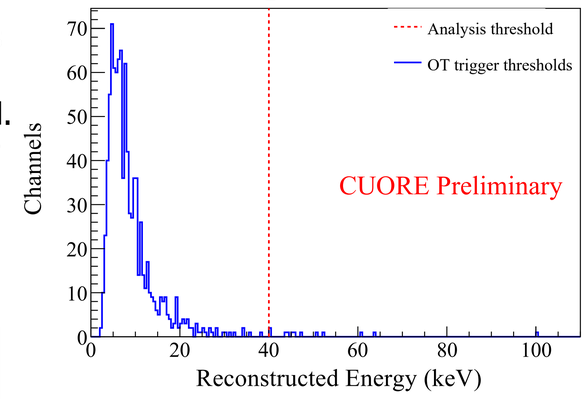
[2]

Low Energy Techniques

The Optimum Trigger (OT) acts on events with amplitudes greater than $N\sigma_f$, which allows lower energy pulses to be detected. Lower thresholds can then be reached for each crystal, increasing sensitivity to low energy signals.

$$\sigma_f^2 = h^2 \sum_k \frac{|s(\omega_k)|^2}{N(\omega_k)}$$



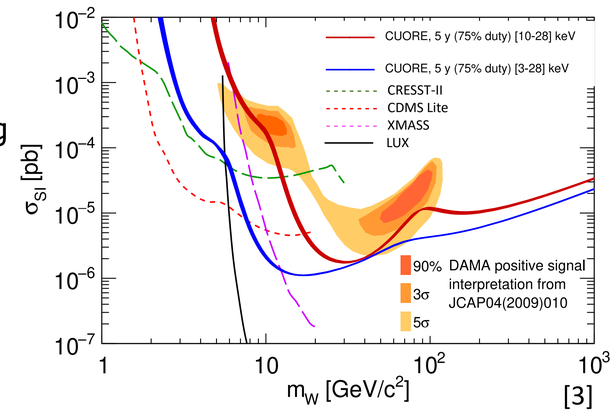


A fit to each filtered pulse comparing an event to the expected signal shape is performed and stored as a goodness of fit metric for each event (χ^2/Shape Indicator). This metric can be applied as a criterion for data selection, which is undergoing finalization for low energy analyses.

In addition, calculation of efficiencies and reconstruction of multiplicity (number of crystals with simultaneous energy depositions) are being considered for low energy analyses.

Dark Matter with CUORE

An annual modulation analysis for Weakly Interacting Massive Particles (WIMPs) is possible due to exposure from detectors with low thresholds. TeO_2 is an interesting target that combines high and low mass nuclei. Low mass WIMPs are targeted for this search due to their larger modulating amplitudes. The sensitivity shown is calculated from detector limitations of CUORE-0 with the expected exposure for CUORE.



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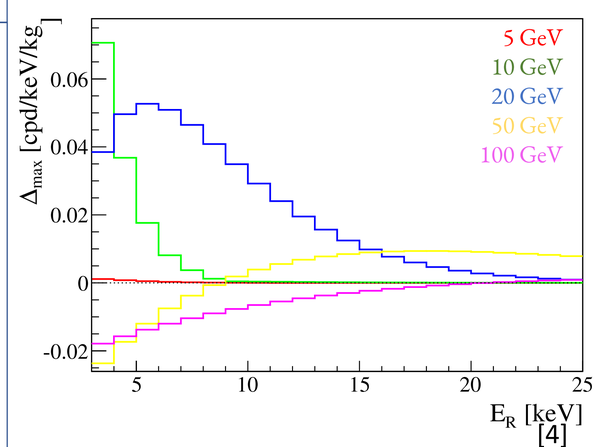
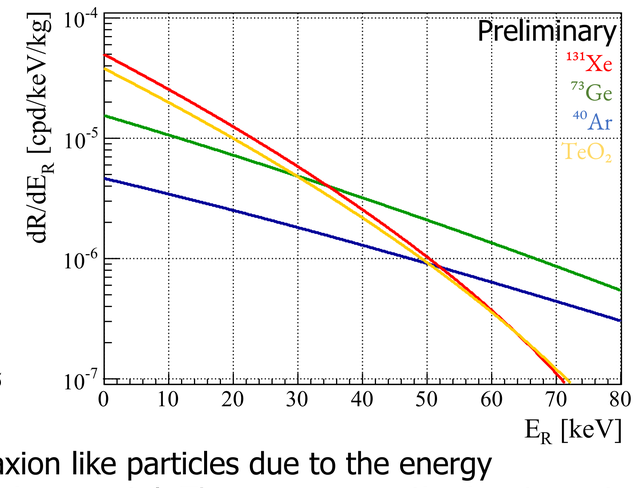
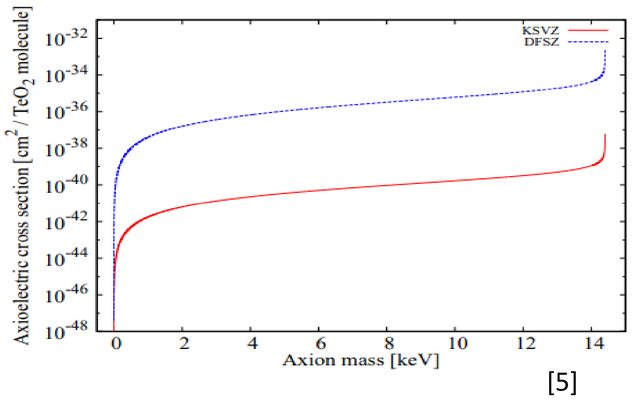




[4]

CUORE can also search for solar axions/axion like particles due to the energy deposition from the M1 transition of ^{57}Fe in a crystal. The monoenergetic signature at 14.4 keV due to the axio-electric effect (in which an energetic axion is absorbed by the target nuclei) can be searched for on top of the exponentially falling background spectrum.



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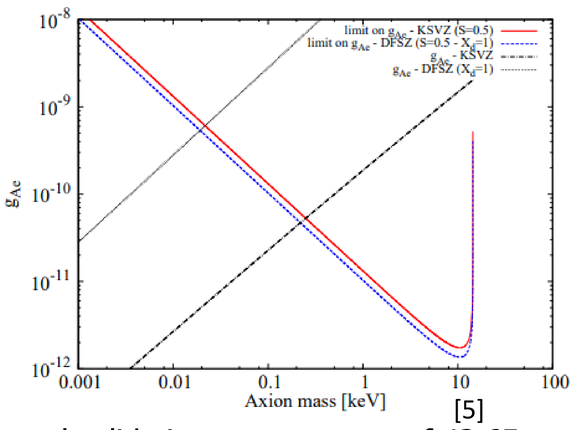

[5]

Sensitivities were calculated with the CCVR2 crystal validation run exposure of 43.65 $kg \cdot d$.

Both WIMP and solar axion analyses will be performed on CUORE's full available exposure, determined after finalization of the low energy data selection and efficiency calculations. Ongoing studies are underway to determine exposure available for low energy searches.

Works Cited

[1] Image courtesy of K. J. Vetter
[2] Ghislandi, S. 2022. *Status and perspectives of the CUORE background model.* [Poster]. Neutrino, 2022, Seoul.
[3] Alduino, C., Alfonso, K., Artusa, D.R. *et al.* Low energy analysis techniques for CUORE. *Eur. Phys. J. C* 77, 857 (2017). https://doi.org/10.1140/epjc/s10052-017-5433-1
[4] Alessandria, F., Ardito, R., Artusa, D. R., Avignone, F. T., Azzolini, O., Balata, M., Banks, T. I., Bari, G., Beeman, J., Bellini, F., Bersani, A., Biassoni, M., Bloxham, T., Brofferio, C., Bucci, C., Cai, X. Z., Canonica, L., Capelli, S., Carbone, L., … Zucchelli, S. (2013). The low energy spectrum of Teo2Bolometers: Results and dark matter perspectives for the cuore-0 and Cuore experiments. *Journal of Cosmology and Astroparticle Physics*, *2013*(01), 038–038. https://doi.org/10.1088/1475-7516/2013/01/038
[5] Search for 14.4 kev solar axions from M1 transition of57fe with cuore crystals. (2013). *Journal of Cosmology and Astroparticle Physics*, *2013*(05), 007–007. https://doi.org/10.1088/1475-7516/2013/05/007