A Search for WIMP Induced Annual Modulation using Low Energy Techniques with CUORE

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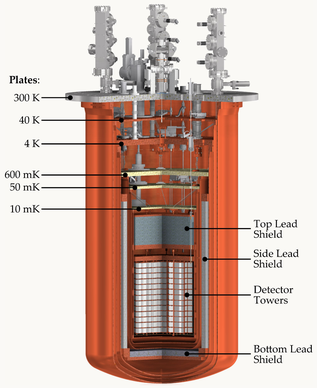
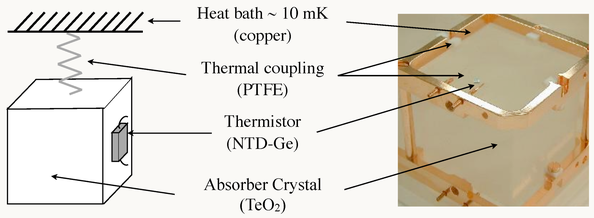
The Cryogenic Underground Observatory for Rare Events (CUORE)

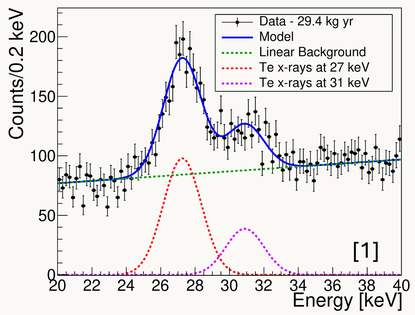
- 742 kg of TeO_2 - 988 crystals operated at ~15 mK as cryogenic calorimeters
- Housed in Hall A of Laboratori Nazionali del Gran Sasso
  - ~3600 w.m.e. overburden + lead shielding
- Designed to search for neutrino-less double beta decay of ^{130}Te
  - Q-Value of ~2527 keV
  - Collected > 3 tonne · yr exposure of TeO_2



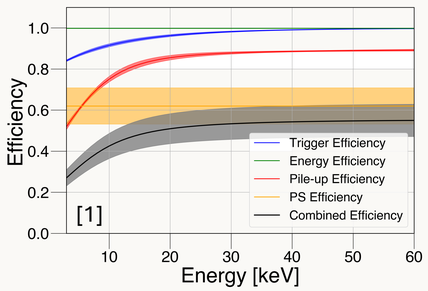


Low Energy Detector Response

- Measure detector resolution using baseline resolution and Te X-rays
  - Energy calibrated with ^{232}Th and ^{60}Co sources
  - X-rays observed at 27 – 31 keV
  - Verify that shift in reconstructed peaks is well within energy resolution

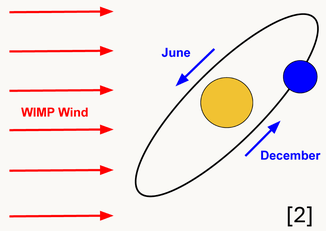


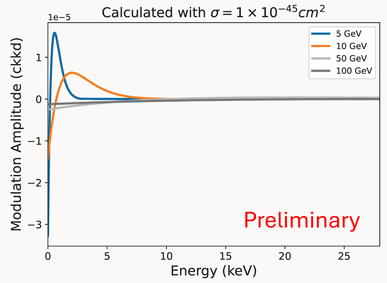
- Evaluate the detector efficiencies with injected thermal signals from Si heaters
  - Inject a variety of low amplitudes to determine the efficiencies as a function of energy

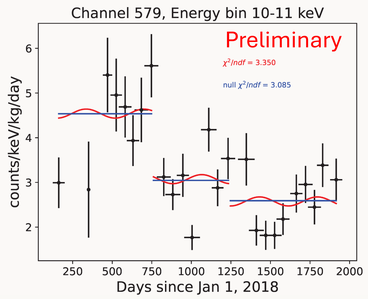


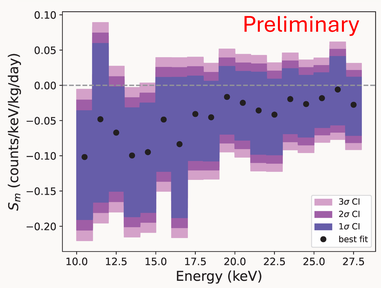
WIMP Induced Annual Modulation

- Weakly Interacting Massive Particles (WIMPs) are a well motivated DM candidate
- Nuclear recoils from Te and O can be observed
  - Produced as Earth travels through isothermally and isotropically distributed DM halo at non-relativistic speeds
- Can search for an annual modulation in nuclear recoils caused by relative velocities of Earth and Sun
  - Period of one year and maximum of June 2nd
- Search for WIMP DM on top of non-negligible background in low energy ROI





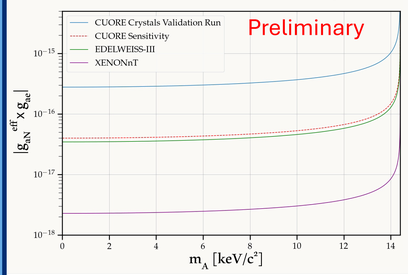




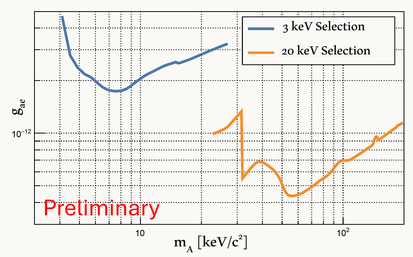
Additional Low Energy Searches: Axions

- Solar axions produced from M1 transition of ^{57}Fe can be detected through axio-electric effect with a mono-energetic signature at 14.4 keV
- Galactic axions composing DM halo can be detected through axio-electric effect with mono-energetic signature at $E \approx m_A$ due to non-relativistic speeds

Solar Axion Sensitivity

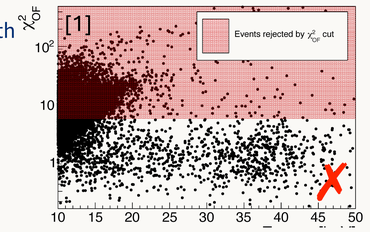


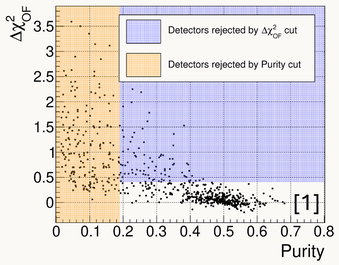
Galactic Axion Sensitivity

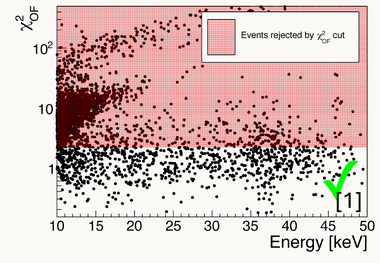


Low Energy Event Selection

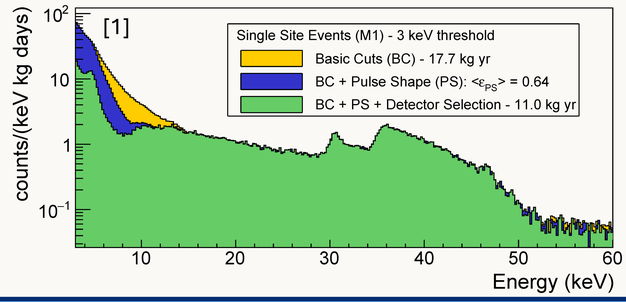
- Average detector threshold is ~7 keV
- Near threshold data is populated with contamination from spurious noise and have worse signal to noise ratio
- Develop selection techniques based on pulse shape variable χ^2_{OF}
  - Difference between Optimum Filtered (OF) pulse [3] and an average pulse template







- Determine channels that can easily discriminate between good quality signal pulses and noise events by comparing data in a low energy region of interest (ROI) and a higher energy reference (REF) region populated with signal events
- Select channels with high signal purity in ROI and a low difference in χ^2_{OF} between ROI and REF that maximize signal significance, increasing exposure and decreasing number of unphysical background events in the low energy ROI



References

[1] CUORE Collaboration. "Exploring the keV-scale Physics Potential of CUORE." *Physical Review D,* vol 113, p. 012012, APS Physics, doi.org/10.1103/fv25-bfgx.

[2] K. Freese, M. Lisanti, and C. Savage. "Colloquium: Annual modulation of dark matter." *Reviews of Modern Physics,* vol 85. doi.org/10.1103/RevModPhys.85.1561.

[3] E. Gatti and P. F. Manfredi. "Processing the Signals From Solid State Detectors in Elementary Particle Physics." *La Rivista del Nuovo Cimento*, vol 9. doi.org/10.1007/BF02822156