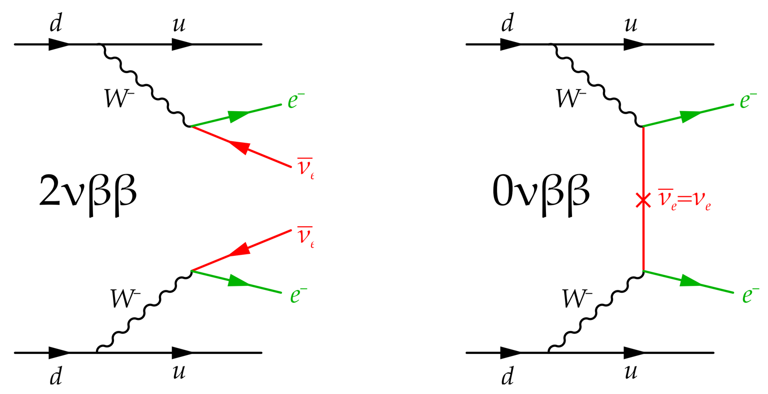
Initial performance of the CUORE detector

Jeremy S. Cushman* for the CUORE Collaboration
*Wright Laboratory, Department of Physics, Yale University, New Haven, CT 06520

Overview

Neutrinoless double-beta decay

Neutrinoless double-beta ($0\nu\beta\beta$) decay is a hypothesized lepton-number-violating nuclear decay in which two electrons and no neutrinos are released from an atomic nucleus.

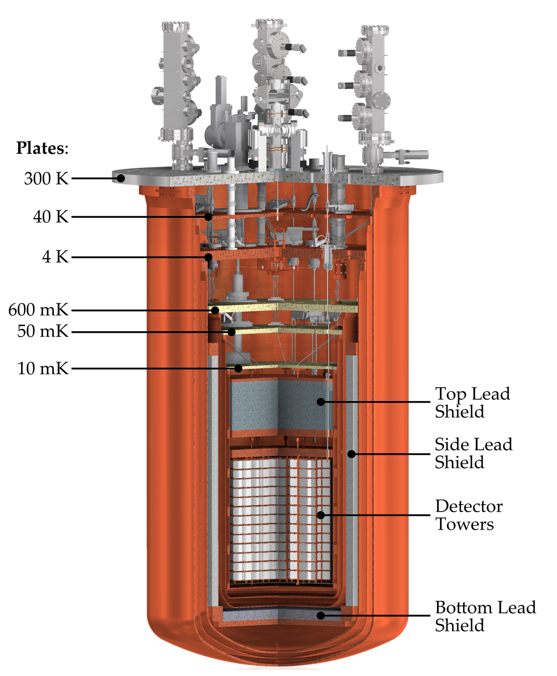


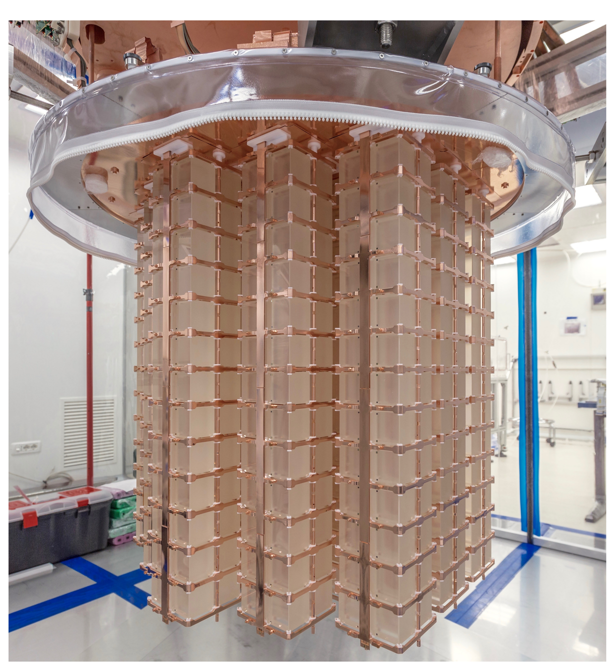
The observation of $0\nu\beta\beta$ decay would:

- Establish that neutrinos are Majorana particles
- Be the first evidence of lepton number violation
- Allow us to determine the effective Majorana neutrino mass of the electron neutrino

CUORE

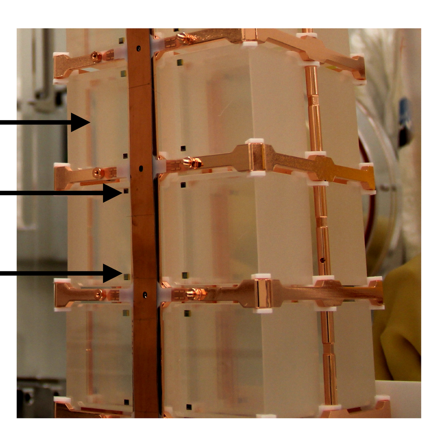
- The Cryogenic Underground Observatory for Rare Events (CUORE) is searching for $0\nu\beta\beta$ in ^{130}Te ($Q = 2527.515$ keV)
- Located deep underground (~3600 m.w.e) at the Laboratori Nazionali del Gran Sasso (LNGS) in Assergi, Italy
- Composed of 988 TeO_2 crystals, arranged into 19 towers
- TeO_2 crystals are the $0\nu\beta\beta$ source material and are operated as bolometric detectors at ~15 mK
- Total detector mass of 742 kg, with 206 kg of ^{130}Te





Detectors

- Each detector tower contains 4 columns, each with 13 crystals
- Each crystal is instrumented with a Neutron Transmutation Doped germanium (NTD-Ge) thermistor and a silicon heater
- The frame of the tower is copper, and the crystals are thermally coupled to the copper with PTFE supports



- Energy depositions in the TeO_2 crystals are measured by continuously recording the voltage across each thermistor
- Each pulse in the detector is filtered, digitized, and saved
- The amplitude of each pulse is proportional to the energy deposited in the crystal
- The bolometers take approximately 5 seconds to recover their baseline temperature after each pulse

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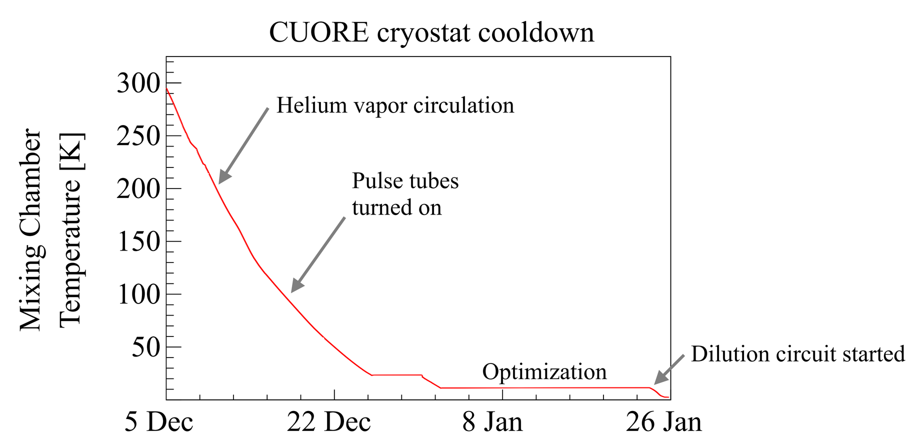
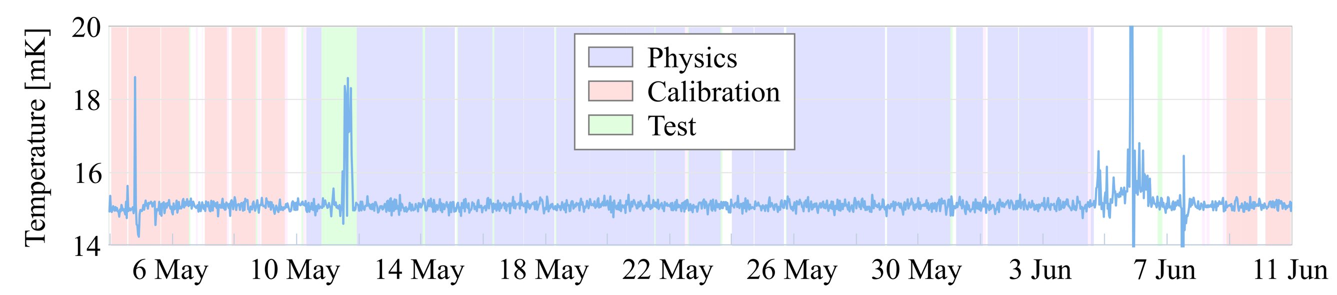
CUORE cryostat

Cryogenics

- CUORE is operated in a cryogen-free cryostat that cools several tons of material to cryogenic temperatures
- Liquid helium vapor used to cool the cryostat to ~50 K
- Pulse tube cryocoolers cool detectors to ~4 K
- Dilution refrigerator can cool detectors to below ~10 mK, with 3 μW of power at 10 mK



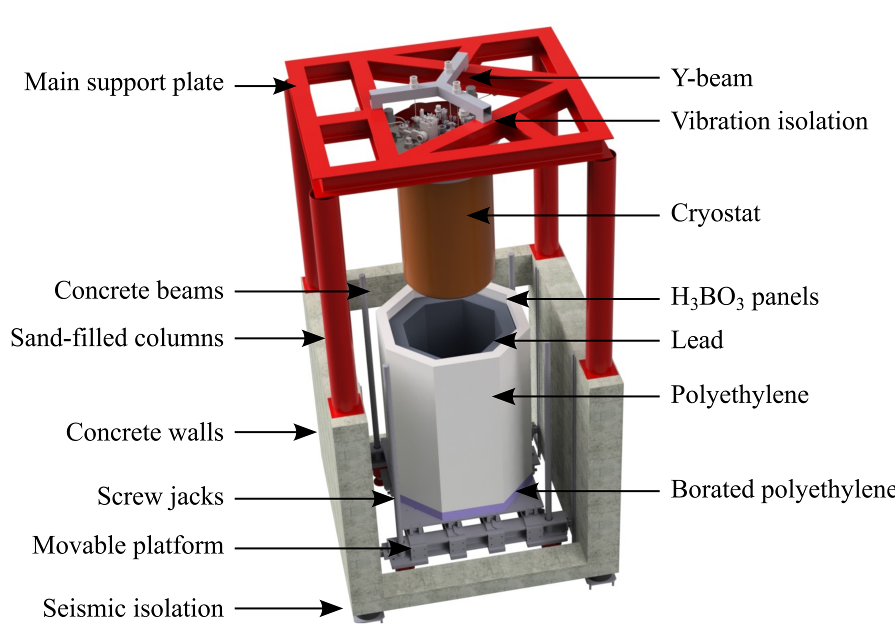
- Detector temperature is stable to within ~0.25 mK during data taking, as measured by a noise thermometer



Noise reduction

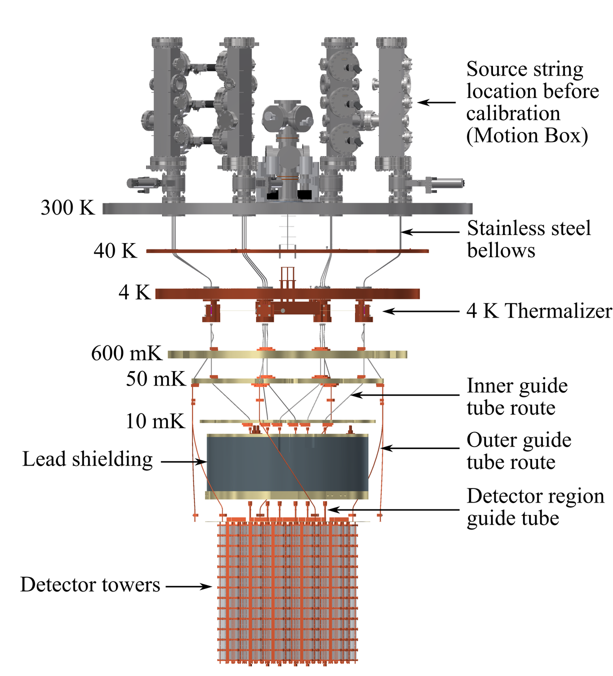
- We have employed a variety of strategies to minimize noise through vibration isolation
- The pulse tube system is a primary contributor to noise, which is mitigated through the use of a sandbox, cold mechanical decouplers, active phase cancellation between the 5 pulse tubes, and remote motor heads suspended independently from the cryostat

External shielding

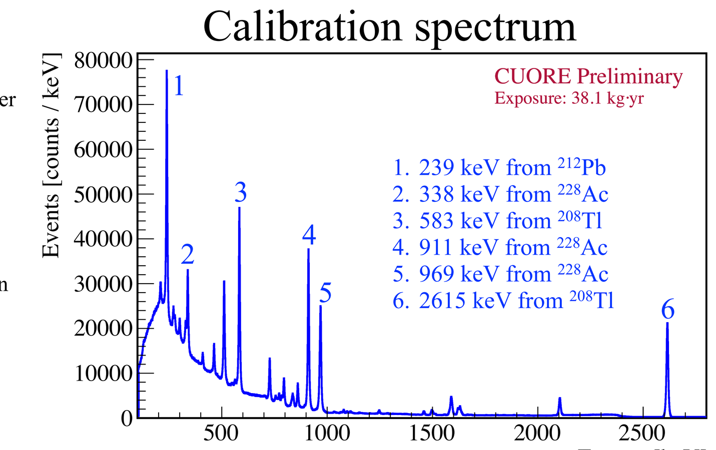


Calibration

Calibration hardware



- An automated system lowers warm ^{232}Th calibration sources into the cryostat and cools them to base temperature monthly

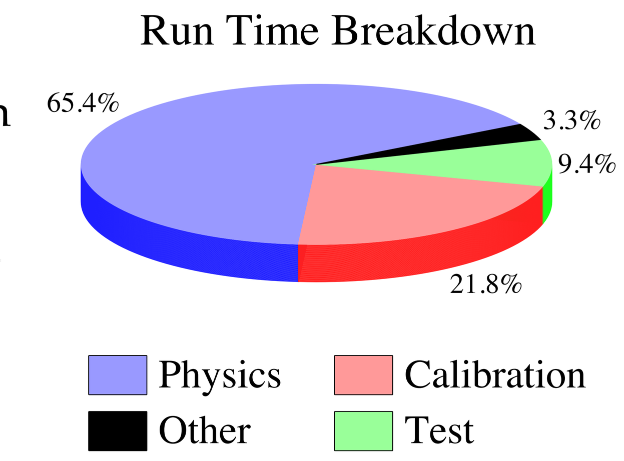


- Several lines from the ^{232}Th decay chain are used to calibrate the CUORE detectors

Data acquisition

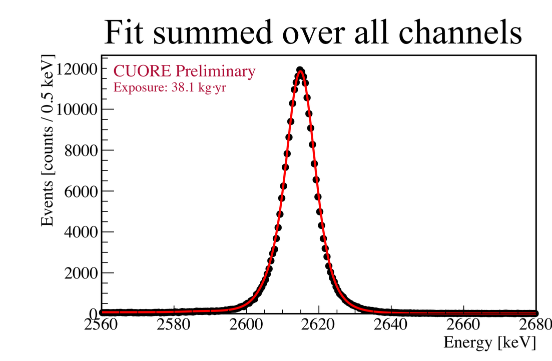
First dataset

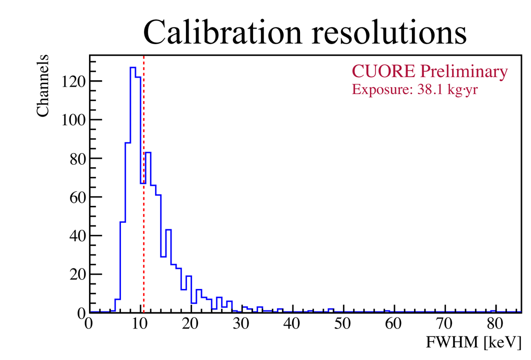
- The first CUORE dataset was acquired in May and June 2017
- The dataset began and ended with approximately 3 days of calibration with ^{232}Th sources
- 984 of 988 bolometers are functioning (99.6%), and the first analysis is performed with 889 bolometers (90%)
- We acquired 38.1 kg·yr of TeO_2 exposure in total, corresponding to 10.6 kg·yr of ^{130}Te exposure



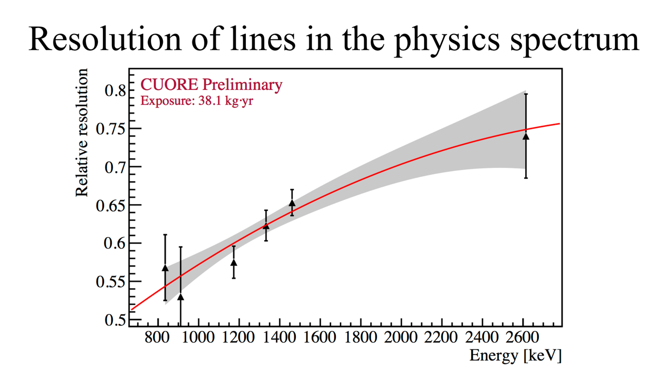
Resolution and energy reconstruction

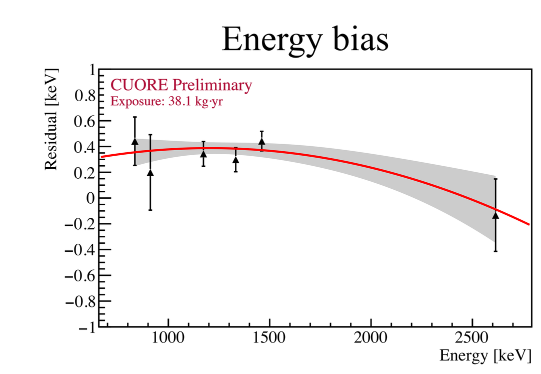
- The resolution and response function of each detector is calculated from a fit to the 2615 keV calibration line





- We estimate the resolution of the physics data by comparing the resolution of the 2615 keV line in physics data to that of calibration data

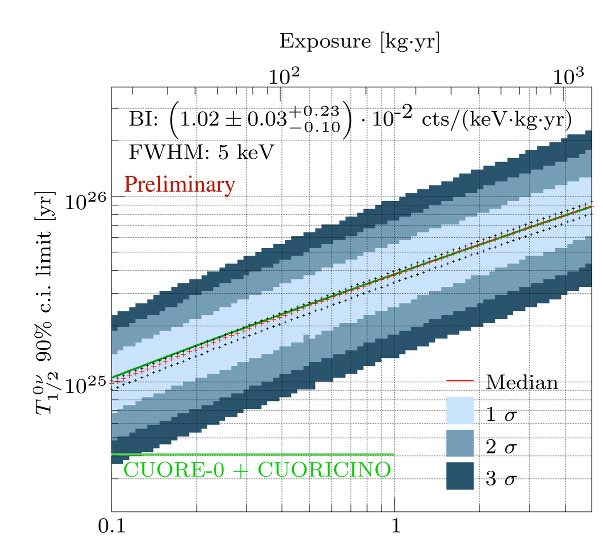


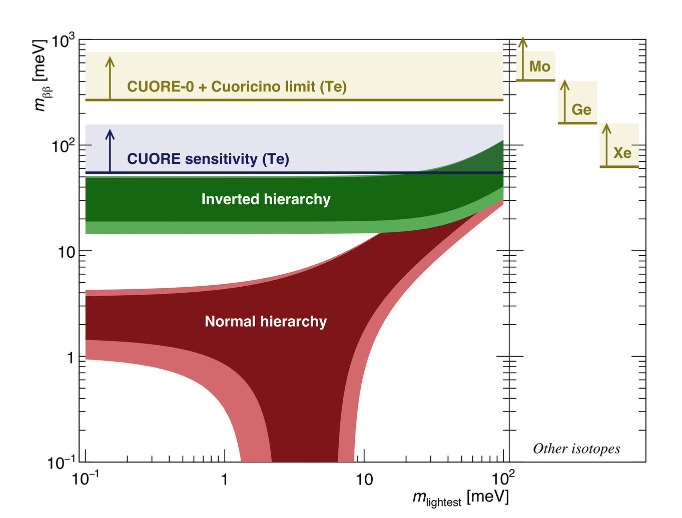


- We estimate our resolution at $Q = 2528$ keV to be 74% of the resolution of the 2615 keV calibration line, and the energy reconstruction to be accurate within 0.5 keV
- We are exploring several promising paths for improving our resolution through noise reduction and improved data processing

Sensitivity

- CUORE has started taking physics data and plans to accumulate 5 years of live time over the course of the experiment
- Our expected 5-year sensitivity is $T_{1/2}^{0\nu} > 9 \times 10^{25}$ yr





CUORE

https://cuore.lngs.infn.it