Cryogenic Verification of the CUORE Detector Calibration System
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Overview
- The search for neutrinoless double beta decay (0ββ) is the only currently feasible way to test the hypothesis that neutrinos are Majorana particles.
- The total energy of the electrons in 0ββ events is fixed at a specific value, the Q-value, which is the difference in binding energy between the initial and final nuclei.
- If the 0ββ half-life can be measured in any nuclide, the effective Majorana mass of the electron neutrino can also be deduced, by way of various theoretical models.

Detector Calibration System
- Bolometers require independent energy calibration.
- Calibration sources must be inside cryostat only during calibration.
- Inserting sources does not affect bolometer temperature.
- Procedure must be stable over expected 5-year lifetime of the experiment.
- Background contribution of calibration hardware must be low (<0.01 counts/keV/kg-year).

Design and Implementation
- Twelve source strings:
  - Move under their own weight.
  - Lowered into the cryostat during operation.
  - Cooled from 300 K to the bolometer region at ~10 K.
- Each source string contains:
  - 25 source capsules of thoria-doped tungsten wire (containing 0ββ).
  - 8 weight capsules.
  - PTFE guide ball.

CUORE
- The Cryogenic Underground Observatory for Rare Events (CUORE) will search for 0ββ in [19K].
- The experiment is located deep underground at the Laboratori Nazionali del Gran Sasso (LNGS) in Assergi, Italy.
- CUORE is composed of 984 TeO₂ crystals, which serve as both the 0ββ sources and as bolometric detectors, ultra-low temperature devices that measure the energy of incident particles via a rise in temperature.
- The high-resolution crystal bolometers, with a total mass of 741 kg and 206 kg of 39Ar, will be operated at 10 mK.
- CUORE is distinguished from other 0ββ searches by the high natural isotopic abundance of 39Ar, the Q-value of 39Ar decay above the Compton edge of the dominant gamma background (263.5 keV from 39Ar), and the high resolution of TeO₂ bolometers.

Energy Calibration
- Voltage signals from the thermometers must be calibrated to determine the energy of each event.
- A two-step calibration process will be used: first the thermometer gain is stabilized and then the thermistor readings are calibrated to absolute energies.
- Both approaches were verified in the operation of CUORE-I, its predecessor experiment.

Results
- One of four complete calibration system modules was installed on the cryostat, and the sources were steadily lowered into, held in, and extracted from the detector region.
- We have verified that the calibration mechanism cools down the source capsule to 4 K.
- We discovered that overnight pre-cooling of the source capsules reduces the time required for cooling and reduces the temperature rise of the cryostat’s 4 K plate.
- We have determined the optimal cooling phase for effectively cooling down the source capsules.

Source Capsule Cooling
- Source strings are lowered into thermometers and mechanically squeezed.
- Two capsules are cooled per capsule, and the string is then lowered for the next capsule.
- This procedure was repeated with an initial 12-hour “parking” period, where the bottom of the source string was held in the thermometer before the sources were lowered further.

Thermalizer Squeezing Force
A force of 31.8 N cools the capsule to base temperature in approximately 30 seconds.

4 K Test Results
Goals
- A cryogenic test of the calibration system was performed at 4 K for:
  - Ensure that source strings can be lowered, cooled by mechanical squeezing, and extracted.
  - Determine an appropriate squeezing force for the thermometer.
  - Estimate the time required for cooling down all of the source capsules.
  - Determine whether “pre-cooling” the capsules in the upper region of the cryostat before lowering them can reduce cooling time without introducing excess background events in the detector.

Schematic of Thermalizer Mechanism

Collaboration
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