The energy calibration system of the CUORE double beta decay bolometric experiment

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on behalf of the CUORE collaboration

see also, on CUORE, Thomas Bloxham
in Session G14, Sunday morning
Two electrons sum energy (keV)

Neutral double beta decay ($\beta\beta^0\nu$) could be the key to answering some of the open questions of neutrino physics:

- absolute mass and hierarchy of masses
- Dirac or Majorana particles?

Our candidate $\beta\beta^0\nu$ nuclide is $^{130}\text{Te}$

$Q_{\beta\beta^0\nu}(^{130}\text{Te}) = 2527.01 \pm 0.32$ keV

Sciellzo et al., nucl-ex/0902.2376

$Q_{\beta\beta^0\nu}(^{130}\text{Te}) = 2527.518 \pm 0.013$ keV

Redshaw et al., nucl-ex/0902.2139

Experimental signature:
peak at the transition $Q$ value, enlarged by detector resolution, over the unavoidable background due to $\beta\beta^2\nu$

$$T_{1/2}^{0\nu} \sim \frac{1}{G^{0\nu} |M^{0\nu}|^2 \langle m_{ee} \rangle^2}$$

phase space factor
nuclear matrix elements

$$\langle m_{ee} \rangle = \left| \sum_{i=1}^{N} \lambda_i |U_{ei}|^2 m_i \right|$$
effective Majorana neutrino mass
The absorber is a 5x5x5 cm$^3$ (790 g) crystal of TeO$_2$ which contains the $\beta\beta0\nu$ candidate $^{130}$Te.

The thermal signal is measured by means of an NTD Ge Thermistor.

$$R(T) = R_0 e^{\sqrt{\frac{T_0}{T}}}$$

An electrical read-out converts resistance changes into voltage pulses.

$\Delta T \sim 100 \, \mu\text{K/MeV}$
Cuoricino

Operated at GranSasso Underground Laboratory (Italy) from 2005 to 2008

44 5x5x5 cm³
and 18 3x3x6 cm³ TeO₂ crystals

detector mass: 40.7 kg;

¹³⁰Te mass: 11 kg

CUORICINO Updated Result

- Use new more accurate Q-value
- Updated statistics through Jan 2008

(total exposure ~ 18 yr*kg ¹³⁰Te):

$$T_{1/2}(90\% \text{ C.L.}) \geq 2.9 \times 10^{24} \text{ yr}$$
CUORE: Cryogenic Underground Observatory for Rare Events will be a tightly packed array of 988 bolometers - M ~ 200 kg of $^{130}\text{Te}$

- Operated at Underground Gran Sasso laboratory (Italy)

CUORE Goals

- Average FWHM resolution: 5 keV
- Background in DBD region: 0.01 counts/keV/kg/y
- Predicted limit after ~5 years of running:
  \[ T_{1/2} \sim 2.1 \times 10^{26} \text{ yr} \quad \Rightarrow \quad <m_\nu > \leq (45 - 70) \text{ meV} \]

Calibration of bolometers

• Bolometer are operated as perfect calorimeters
  – energy is the most relevant information extracted
• For each bolometer:
  – Voltage vs Energy relationship is needed
  – Calibration with γ sources of known energies (e.g. 232Th)
  – The pairs (E_i,V_i) are fitted with a proper calibration function
  – The calibration measurement is performed regularly (~ monthly)

• The calibration uncertainty
  – affects the resolution of the detectors
  – is one of the systematic errors in the determination of the \( \beta\beta 0\nu \) half life

![Graph showing peak identification and fit of calibration function](image)
**CUORE calibration**

- **Uniform illumination** of all detectors with 5 calibration lines clearly identified in the energy spectrum between 511 keV and 2615 keV

![Sum calibration spectrum of Cuoricino with $^{232}$Th source](image)

- **Sources can be replaced.** Other source isotopes can be used if necessary (e.g. $^{56}$Co has been studied)

- **Calibration time** does not significantly affect detector live time

- **Negligible contribution to radioactive background** in the $\beta\beta0\nu$ region

- **Minimize the uncertainty** in the energy calibration. Goal: residual calibration uncertainty in $\beta\beta0\nu$ region < 0.05 keV
CUORE calibration system

Insertion of 12 $\gamma$ sources that are able to move, under their own weight, through a set of guide tubes that route them from the deployment boxes on the 300K flange down into position in the detector region.

**source locations**

top view of detector array with source positions

**source locations**

40K
300K
4K
0.7K
70mK
10mK

Lead shield

Lead shield

computer controlled motion box for source deployment

radioactive capsules crimped on a Kevlar string

Teflon cover

guide tubes

detectors

232Th or $^{56}$Co

~1.6mm

~10mm

Teflon cover
Prototype tests

- Source string goes down along guide tubes under its own weight
- Load cell output allows to monitor source position along the guide tube routing

![Lab mock up of guide tube routing](image)

![Graph of Load cell vs. # of turns of spool](image)
Cryogenic considerations

Sources of heat load:
- Conductance of the guide tubes
- Radiation funneled by guide tubes
- Conductivity of source string
- Radiation emitted by the source string
  - cooling mechanism required
- Friction during insertion/extraction
  - low friction materials + speed adjustment

<table>
<thead>
<tr>
<th>Stage</th>
<th>T [K]</th>
<th>Cooling power available to calibration [W]</th>
<th>Static heat load from guide tubes</th>
<th>Radiation from source string at 4K</th>
</tr>
</thead>
<tbody>
<tr>
<td>40K</td>
<td>40 – 50</td>
<td>~ 1</td>
<td>~ 1</td>
<td>--</td>
</tr>
<tr>
<td>4K</td>
<td>4 – 5</td>
<td>0.3</td>
<td>0.02</td>
<td>--</td>
</tr>
<tr>
<td>0.7K</td>
<td>0.6 – 0.9</td>
<td>0.55m</td>
<td>0.13m</td>
<td>0.07µ</td>
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<tr>
<td>700mK</td>
<td>0.05 – 0.1</td>
<td>1.1µ</td>
<td>negligible</td>
<td>0.1µ</td>
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<tr>
<td>10mK</td>
<td>0.01</td>
<td>1.2µ</td>
<td>1.07µ</td>
<td>0.065µ</td>
</tr>
<tr>
<td>detector</td>
<td>0.01</td>
<td>&lt; 1µ</td>
<td>--</td>
<td>0.05µ + 0.5µ</td>
</tr>
</tbody>
</table>

Scheme of guide tube materials and thermal couplings

- Stainless Steel
- Copper
  - Perfect thermal coupling
  - Weak thermal coupling

internal | external

Detector
Cooldown of the sources

- Sources must be cooled to < 4K to meet heat load requirements
- Strong mechanical contact is needed between the source carrier and a heat sink at 4K

Squeezing mechanism

- Iso view
- Side view

Components:
- Detector region
- Lead shield
- 40K
- 300K
- 4K
- 0.7K
- 70mK
- 10mK
- Solenoid linear actuator
- Source string
- Pushing blade
Friction during source insertion/extraction

Sliding friction +

Friction of a string on a fixed rod

\[ \frac{T_2}{T_1} = e^{\mu_k \beta} \]

- Exponential dependence on angle and friction coefficient

- Each guide tube routing has several bends and sloped sections

- Optimal sequence of staggered source extraction at variable speed to meet heat load requirements

- Simulated heat load, source speed = 0.1 mm/s

- Power dissipated [W] during extraction at constant speed

Distance traveled by source [m]
Conclusions

• The successful operation of CUORE, in the search for neutrinoless double beta decay, requires a reliable and efficient energy calibration system.

• The design of the calibration system is technically challenging and stringent requirements must be met, in particular when it comes to the integration in the unique CUORE cryostat.

• The design of the calibration system for CUORE is being finalized and prototype parts are currently being tested.