The CUORE and CUORE-0 Experiments at Gran Sasso

Andrea Giachero

University and INFN of Milano – Bicocca

On behalf of CUORE collaboration

ICNFP 2014, 28th July - 6th August 2014, Crete, Greece
The CUORE Collaboration

- 19 groups:
  - Italy
  - USA
  - China
  - France
- 148 collaborators
- 117 researchers
Experimental search for $0\nu\beta\beta$

**What we are looking for**

- $2\nu\beta\beta$: $N(A,Z) \rightarrow N(A,Z+2) + 2e^- + 2\nu_e$
  - allowed in the SM and already observed with $T_{1/2} > 10^{18}$y in several nuclei

- $0\nu\beta\beta$: $N(A,Z) \rightarrow N(A,Z+2) + 2e^-$
  - not allowed in the SM
  - expected with $T_{1/2} > 10^{25}$y

---

**Experimental Approach**

$Source \subseteq Detector$

**Signature:**

- Peak at $Q_{\beta\beta}$-value over $2\nu\beta\beta$ tail
- enlarged only by detector resolution.

---

**Experimental Sensitivity**

Lifetime corresponding to the minimum detectable number of events over background at a given C.L. (*):

$$S^{0\nu}_{1/2} \propto \epsilon \cdot \text{i.a.} \cdot \sqrt{M \cdot t / \Delta E \cdot B}$$

- $M$: Total active mass in kg
- $\epsilon$: Detector efficiency
- i.a: Isotopic abundance
- $B$: Background in c/keV/kg/y
- $\Delta E$: Energy resolution @ ROI in keV
- $t$: Exposure time in y

(\*) Qualitative expression in the Gaussian approximation (not fully accurate for very low background experiments)
The Bolometric Technique

**Bolometer:** a particle detector that measures the energy deposited by incident radiation based on the temperature change

It generically consists of three parts:

- **Heat bath:** weak thermal link connecting the absorber to a thermal reservoir;
- **Phonon Sensor:** the active part that converts the excitation into an electrical signal;
- **Energy Absorber:** the sensitive part where the incident radiations deposit their energy.

Dielectric and diamagnetic crystals show a low thermal capacity in case of low temperature:

\[ C(T) \propto \left( \frac{T}{T_D} \right)^3 \quad \text{and} \quad \Delta T \propto \frac{\Delta E}{C} \]

**Debye Law**

\( \text{if } C \downarrow \Rightarrow \Delta T \uparrow \)
The Bolometric Technique (cont'd)

Temperature rise $\Delta T$:
- roughly proportional to the energy deposition ($\Delta E$)
- inversely proportional to thermal capacity ($C$) of the material used as absorber

Features

- True calorimeter (100% efficiency)
- Large detection volume
- High intrinsic energy resolution → 5 keV FWHM @ 2615 keV

$^{130}$Te as $0\nu\beta\beta$ candidate

- High natural isotopic abundance: 34.2 %
- Transition energy: $Q \approx 2528$ keV
- Encouraging nuclear matrix element calculations
$^{130}\mathrm{Te}$ $0\nu\beta\beta$ search with $\mathrm{TeO}_2$ bolometers

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mass</th>
<th>$^{130}\mathrm{Te}$</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>MiDBD</td>
<td>1.8 kg</td>
<td>$^{130}\mathrm{Te}$</td>
<td>$T_{1/2}^{0\nu} &gt; 2.1 \times 10^{23}$ y (90% C.L.)$^1$</td>
</tr>
<tr>
<td>Cuoricino</td>
<td>11.3 kg</td>
<td>$^{130}\mathrm{Te}$</td>
<td>$T_{1/2}^{0\nu} &gt; 2.8 \times 10^{24}$ y (90% C.L.)$^2$</td>
</tr>
<tr>
<td>CUORE-0</td>
<td>10.9 kg</td>
<td>$^{130}\mathrm{Te}$</td>
<td>2013 – 2015?? Initial performances$^3$</td>
</tr>
<tr>
<td>CUORE</td>
<td>~206 kg</td>
<td>$^{130}\mathrm{Te}$</td>
<td>2015 - ???? Status Report$^4$</td>
</tr>
</tbody>
</table>

References:


$^2$ E. Andreotti et al., Astrop. Phys. 34 (2011) 822

$^3$ C.P. Aguirre et al., arXiv:1402.0922

$^4$ D.R. Artusa et al., arXiv:1402.6072
The CUORE Experiment

Cryogenic Underground Observatory for Rare Events

Search for the Neutrinoless double beta decay ($0\nu\beta\beta$) in $^{130}\text{Te}$ with 988 TeO$_2$ bolometers

- **Detector**
  - $^{130}\text{Te}$ mass: 206 kg ($\approx 10^{27}$ nuclei)
  - TeO$_2$ mass: 741 kg, 988 crystals
  - TeO$_2$ bolometers arranged in **19 towers**
  - Single crystal: 5x5x5 cm$^3$ (0.75 kg)

- **Goals**
  - Resolution: 5 keV FWHM @ 2.5 MeV
  - Background: **0.01 counts/(keV kg y)**
  - Half life sensitivity: $\tau_{1/2} > 1.6 \times 10^{26}$ y @ 1σ
  - Majorana mass sensitivity: $m_{\beta\beta} \approx (40 \div 100)$ meV

- **Detector cool-down**
  - Spring 2015
**Design goal:**
- bkg: 0.01 counts/(keV·kg·y)
- $\Delta E$: \( \approx 5 \text{ keV FWHM} \)
- $t_{\text{meas}}$: 5 years

$S_{1/2}$ (0νββ):
- $\rightarrow 1.6 \times 10^{26} \text{ y (1\sigma)}$
- $\rightarrow 9.5 \times 10^{25} \text{ y (90\% C.L.)}$

In terms of effective Majorana mass:
- $M_{ee} \approx (40 \div 100) \text{ meV}$
The CUORE Location

Laboratori Nazionali del Gran Sasso
Assergi, L'Aquila (Italy)

- Average depth: ≈ 3650 m.w.e.
- $\mu$ flux: $\approx 3 \cdot 10^{-8}$ $\mu$/s/cm$^2$
- $n$ flux < 10 MeV: $4 \cdot 10^{-6}$ n/s/cm$^2$
- $\gamma$ flux < 3 MeV: 0.73 $\gamma$/s/cm$^2$
The CUORE-0 Experiment

CUORE-0 is one CUORE-like tower:

- 52 TeO$_2$ 5x5x5 cm$^3$ crystals (750 g each);
- 13 planes of 4 crystals each;
- total detector mass: 39 kg TeO$_2$ ($\approx$11 kg of $^{130}$Te);

All detector components manufactured:
- cleaned and stored with the same protocols defined for CUORE
- assembled with the same procedures of CUORE

Goals

- Proof of concept of CUORE detector in all stages;
- Test and debug of the CUORE tower assembly line;
- Test of the CUORE DAQ and analysis framework;
- Extend the physics reach beyond Cuoricinio while CUORE is being assembled;
- Demonstrate potential for DM detection;
CUORE-0 Data taking

CUORE-0 is operated in the 25 years-old Cuoricino cryostat:

- First cooldown in August 2012: problems with cryostat;
- March 2013: start data taking (Phase I);
- October 2013: maintenance stop;
- November 2013: data taking resumed (Phase II) with improved conditions;
- Statistics updated till May 2014;

- Expected to surpass Cuoricino exposure with \( \approx 1 \) year of livetime.
Energy Resolution (Phase II)

- Two thoriated strings illuminate the bolometers on opposite sides of the tower;
- Calibrations performed before and after each data set;
- $\Delta E_{\text{FWHM}} \approx 5 \text{ keV} @ 2615 \text{ keV (Tl line)}$
CUORE-0 Background

Cuoricino background model confirmed:
- environmental γs from material bulk contaminations (cryostat)
- surface contaminations of close materials

Evident reduction with respect to Cuoricino:
- factor of 6 for surface contaminations
- factor of ≈ 2.5 in the ROI

<table>
<thead>
<tr>
<th>Background [counts/(keV kg y)]</th>
<th>Eff [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0νββ region</td>
<td>(2.7 ÷ 3.9 MeV)</td>
</tr>
<tr>
<td>CUORICINO</td>
<td>0.153 ± 0.006</td>
</tr>
<tr>
<td>CUORE-0</td>
<td>0.063 ± 0.006</td>
</tr>
</tbody>
</table>
**CUORE-0 Sensitivity**

The blinding procedure produces an artificial peak in the ROI: a small blinded fraction of the events within ±10 keV of the $^{208}$Tl 2615 keV peak is exchanged with the events within ±10 keV of the $^{130}$Te Q-value.

**Projected sensitivity:**
- Energy resolution (background spectrum - full statistics):
  \[ \Delta E \approx 5 \text{ keV FWHM @ 2615 keV} \]
- Background index (in the 0νββ ROI):
  \[ b = 0.063 \pm 0.006 \text{ cnts/(keV kg y)} \]
CUORE Status

- All 19 towers have been assembled and instrumented
- Stored under nitrogen flushing while waiting to be installed in the cryostat
**CUORE Status: Cryogenics**

**Complex cryogenic setup (h = 3.1 m, Ø = 1.7 m)**

- Fully cryogen free system:
  - custom cryostat;
  - 5 pulse tubes;
  - a powerful dilution refrigerator;
  - \(\approx 10 \text{ mK operating temperature}\);
- Independent suspension of the detector array;
- An embedded detector calibration system;
- Radio-pure materials;
- Heavy low temperature shield;

**Current status:**

- Cryogenic system fully assembled
- Full system tests:
  - first cooldowns with no additional loads;
  - \(T \approx 14 \text{ mK}\) reached;
  - still ongoing tests;
- Expected completion (wires, lead, suspension system):
  \(\rightarrow\) early 2015
CUORE Status

Moving to detector integration (installation into the cryostat)

- very delicate operation (towers exposed to air);
- protected area flushed with Rn-free air;
- dedicated installation tools;
- still copper cleaning;
- detector interfaces;
- detector cage (ultra-cleaning - detector grade);

Detector installation: spring 2015

In the meanwhile all the other systems are being completed and moved to LNGS for installation:

- DAQ;
- Electronics;
- Data analysis tools;
- Faraday cage;

CUORE data taking will start in summer 2015
Conclusion

- CUORE-0 is taking data: it confirms Cuoricino background model and shows that 5 keV resolution is achievable;
- CUORE-0 shows an evident background reduction with respect to Cuoricino;
- CUORE-0 is a competitive experiment on its own;

- CUORE detector is ready;
- CUORE cryogenic system is assembled: first cooldowns to base temperature are ongoing;
- CUORE detector installation foreseen for spring 2015;
- CUORE start expected in summer 2015.

Thank you for your attention
The CUORE and CUORE-0 Experiments at Gran Sasso

Andrea Giachero

University and INFN of Milano – Bicocca

On behalf of CUORE collaboration

Backup Slides

ICNFP 2014, 28th July - 6th August 2014, Crete, Greece
CUORICINO

- 62 TeO$_2$ bolometers
- 41 kg (11.3 kg in $^{130}$Te)
- Statistics: 19.75 kg y in $^{130}$Te
- Resolution: 6.3 keV FWHM
- Bkg: 0.15 counts/(keV kg y) (790 g, big crystals only)

$T_{1/2}^{0\nu} > 2.8 \times 10^{24}$ y @ 90% CL

$m_{\beta\beta} < (300 \div 710) \text{ meV}$

Main background contributions
- Gammas from $^{208}$Tl ($^{232}$Th cont. in cryostat shields): (30±10)%
- Radioactive cont. from crystal surfaces: (10±5)%
- Radioactive cont. from Cu holders surfaces: (50±20)%

Crystal contamination: double hit
Copper contamination: single hit

Calibration spectrum normalized on 2615 keV peak in background spectrum
CUORE Gluing

Semi-automatic gluing system to improve the reproducibility of detector performances

- NTD sensors;
- Joule heaters (for detector gain calibration);

All operations performed in glove boxes to avoid radon recontamination
CUORE Towers assembly

- Copper support structure;
- Teflon supports;
- Crystals;
- Cu-PEN tapes for signal readout;

All operations performed in glove boxes to avoid radon recontamination
CUORE Bonding

Use a bonding machine to connect the sensors and the heaters to the wire tray pads with gold wires.
Energy Resolution (Phase I+II)

- Two thoriated strings illuminate the detectors on opposite sides of the tower;
- Calibrations performed before and after each data set;
- $\Delta E_{\text{FWHM}} \approx 5.7 \text{ keV} @ 2615 \text{ keV}$ (Tl line)
CUORE-0 background spectrum (γ-region)

CUORE-0 Spectrum

1. $e^+e^-$ annihilation
2. $^{214}\text{Bi}$
3. $^{40}\text{K}$
4. $^{208}\text{Tl}$
5. $^{60}\text{Co}$
6. $^{228}\text{Ac}$

Environmental γ lines compatible with Cuoricino observations

→ common cryogenic apparatus
The background in the alpha-dominated region (surface contaminations) is evaluated in the interval (2.7 ÷ 3.9) MeV (excluding $^{190}\text{Pt}$ peak region from 3.2 to 3.4 MeV);

- $B = (0.020 \pm 0.001)$ cnts/keV/kg/y → reduction of a factor ~6 with respect to Cuoricino.