STATUS OF THE CUORE0 AND CUORE EXPERIMENTS

O. Cremonesi
INFN – Sez. Milano Bicocca
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Outline:
- Scientific goal
- Experimental setup
- Status
- CUORE-0
- Conclusions
CUORE

Cryogenic Underground Observatory for Rare Events

Closely packed array of 988 TeO$_2$ crystals 5×5×5 cm$^3$ (750 g)

741 kg TeO$_2$ granular calorimeter

600 kg Te = 203 kg $^{130}$Te

19 towers
13 planes each
4 crystals each

Calorimetric experiment on $^{130}$Te neutrinoless DBD

<table>
<thead>
<tr>
<th>Background</th>
<th>$\Delta E$</th>
<th>$T_{1/2}$</th>
<th>$&lt;m_{\beta\beta}&gt;$</th>
</tr>
</thead>
<tbody>
<tr>
<td>c/kev/kg/y</td>
<td>keV</td>
<td>$10^{26}$ y</td>
<td>R(QRPA)$^1$</td>
</tr>
<tr>
<td>0.01</td>
<td>5</td>
<td>2.1</td>
<td>35-66</td>
</tr>
<tr>
<td>0.001</td>
<td>5</td>
<td>6.5</td>
<td>20-38</td>
</tr>
</tbody>
</table>

1 Śimkovic et al., PRC 77 (2008) 045503
2 Civitarese et al., JoP:Conference series 173 (2009) 012012
3 Menéndez et al., NPA 818 (2009) 139
4 Barea and Iachello, PRC 79 (2009) 044301

Single cryogenic setup ($T_{\text{work}}=10-15$ mK)

Complex system of radiation shields
Mechanical decoupling system
Detector calibration system
Underground laboratory (LNGS)

Dark Matter search potential → F.Bellini talk

O.Cremonesi - 24/09/2012 NPB 2012 @ Shenzhen
The CUORE Collaboration
TeO2 bolometers evolution

$\Delta E = 6.2 \pm 2.5\text{ keV} \ (\sim 0.3\% \ FWHM)$

Bkg = $0.169\pm0.006\text{ c/keV/kg/y}$

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

NME from F.Simkovic et al. Phys.Rev. C77
J.Menendez et al. Nucl. Phys. A818
J.Barea et al. Phys. Rev. C79
**ββ0ν experimental sensitivity**

\[ S^{0\nu}_{1/2}(m_{ee}) \propto \frac{i.a.}{A} \frac{1}{\sqrt{G^{0\nu}}|M^{0\nu}|} \frac{4}{M \cdot t_{meas}} \sqrt{bkg \cdot \Delta E} \]

- **Isotope choice**
- **Mass**
- **Energy resolution**
- **Background level**
- **Long measure time**

- Deep underground location
- Bolometric approach
- Large mass array
- Material selection
- Severe control of procedures
- Stable operating condition over several years

**ββ candidate:** $^{130}$Te $-$ Q 2527.5 keV

**Source Mass:** 206 kg $^{130}$Te $-$ N$_{ββ}$ 9.6 x10$^{26}$

**Projected Bkg:** 0.01 c/keV/kg/y

**Resolution:** ~ 5 keV @ROI

**Sensitivity T$_{1/2}^{0\nu}$:** 1.6x10$^{26}$ y in 5 y

**Sensitivity <m$_{ee}$>:** $<m_{ee}> < 40 \div 94$ meV in 5y (IH)
The LNGS underground facility

- CUORE hut (New Building)
- Cuoricino/CUORE-0 hut

Underground facility
- Average depth ~ 3650 m.w.e.
- Factor $10^6$ reduction in muon flux to 
  $\sim 3 \times 10^{-8} \mu/(s\cdot cm^2)$
The CUORE TeO$_2$ bolometers

- Heat sink (8-10 mK)
- Cu holder
- PTFE supports (G)
- TeO$_2$ crystal
- NTD Ge sensor
- Incident radiation (E)

Pros:
- good energy resolution
- different sources could be investigated
- high efficiency (internal sources)

Cons:
- no dead layer
- low temperature tech required
- slow pulses

$\Delta T = \frac{E}{C}$

$\tau = \frac{C}{G}$

$T \sim 1 \text{s}$

O.Cremonesi - 24/09/2012 NPB 2012 @ Shenzhen
Background contributions

Largest available statistics: Cuoricino

But a lot of information comes also from dedicated R&D bolometric measurements in an R&D cryogenic setup @ LNGS
R&D and QC tests

- TTT (Three Tower [cleaning] Test)
- RAD (RADioactivity study setup)
- CCVR (CUORE crystal validation runs)

• No way of measuring directly the background level in the $\beta\beta_{0\nu}$ ROI
• Background model needed
Background model

MC: the background in CUORICINO is due to degraded alpha particles which release only part of their energy in the detector (surface contamination)


Bkg @ 0vDBD region = 0.161 +/- 0.006 c/keV/kg/y (ainticoincidence spectrum, 5x5x5 cm³ crystals)


30 ± 10 % ²³²Th in cryostat (γ)
10 ± 5 % TeO₂ surface (α)
50 ± 20 % Cu surface (α)
### Background budget

<table>
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<tr>
<th>Source</th>
<th>CUORE in the ROI ( \text{c/(keV kg y)} )</th>
<th>Source of data</th>
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<td>Cosmogenic activation of crystals (bulk)</td>
<td>( \sim 1 \times 10^{-3} )</td>
<td>NAA + MC</td>
</tr>
<tr>
<td>Gold wires ( {^{232}\text{Th} and {^{238}\text{U}}} ) (bulk)</td>
<td>( &lt; 1 \times 10^{-3} )</td>
<td>Bolometric test + HPGe</td>
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<tr>
<td>Copper frames ( {^{232}\text{Th}} ) (bulk)</td>
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<td>HPGe + NAA + MC</td>
</tr>
<tr>
<td>( {^{232}\text{Th}} ) in the Roman lead shield (bulk)</td>
<td>( &lt; 4 \times 10^{-3} )</td>
<td>Bolometric + HPGe</td>
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<tr>
<td>Muon interactions (bulk)</td>
<td>( \sim 1.8 \times 10^{-3} )</td>
<td>Measured fluxes + MC</td>
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<tr>
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<td>( &lt; 2-3 \times 10^{-2} )</td>
<td>Test on small tower + MC</td>
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<td>( &lt; 6 \times 10^{-2} )</td>
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If contamination in the R&D run are due to surface contamination of copper structure

mutually exclusive hypotheses!

If contamination in the R&D run are due to \( {^{210}\text{Pb}} \) contamination of PTFE (unlikely)

new measurement in progress

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**Conservative values**
- Different depth profiles of surface contaminations compared and largest values quoted here

**Upper limits**
- Attribute all events in the target region as due solely from a certain source

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CUORE sensitivity

Background goal of 0.01 c/keV/kg/y

$$T_{1/2} = 1.6 \times 10^{26} \text{ y} \quad m_{\beta\beta} = 41-95 \text{ meV}$$
Background goal of 0.01 c/keV/kg/y

\[ T^{0}_{1/2} = 1.6 \times 10^{26} \text{ y} \quad m_{\beta\beta} = 41-95 \text{ meV} \]

The large mass and excellent energy resolution, make CUORE competitive to sound the IH region down to 41-95 meV.
CUORE experimental setup

Custom cryogenic system @ LNGS.
- Improved shielding and material selection.
- High efficiency in background rejection, due to the packed geometry: minimum lead thickness surrounding the detector ~ 36 cm
- No cryogenics liquids: better duty cycle
- Mechanical suspension of the detector assembly completely independent from the refrigeretor structure: better control of noise induced by vibrations
- Severe control of the radioactivity of the set-up

Embedded in the setup (after a severe control of the radioactivity of the materials):
- Cryo-free dilution refrigerator (Leiden Cryogenics)
- Roman Lead (no 210Pb) cold shield
- Detector and Pd shielded suspension
- Calibration system
Detector Calibration System

- 12 gamma source wires
  - $^{232}$Th: thoriated tungsten wire
  - $^{56}$Co: proton activated Fe wire
- Minimize down time but rate at each crystal not exceeding 150 mHz
- Stringent heat load requirement

O.Cremonesi - 24/09/2012 NPB 2012 @ Shenzhen
An improved tower design

- Copper Frame:
  - Heat bath
  - Background source

- Teflon holders
  - The weak thermal link
  - Reduce vibration noise
Set of specially designed Glove Boxes
- Rn free atmosphere
- strict control of materials
- reproducible protocol

Completed Summer 2011
CUORE status & schedule

Detector
- Crystals, almost completely delivered at LNGS
- Copper parts machining and cleaning are progressing regularly
- Tower assembly line was completed in 2011 and tested on CUORE0. Ready to start for the CUORE tower assembly in November 2012
- Radon abatement system installed

CUORE Hut, and most of all the infrastructures are ready

Cryogenics
- Dilution unit delivered to LNGS. Performance better than expected.
- 3 (of 6) cryostat vessels tested and delivered at LNGS
- Commissioning of the cryogenic setup started on July 2012

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<tr>
<td>Crystals</td>
<td>12/12</td>
</tr>
<tr>
<td>Thermistors</td>
<td>13/03</td>
</tr>
<tr>
<td>Cleaned Cu parts</td>
<td>13/12</td>
</tr>
<tr>
<td>Cryogenics</td>
<td>13/12</td>
</tr>
<tr>
<td>Tower Assembly</td>
<td>14/04</td>
</tr>
<tr>
<td>Detector insertion</td>
<td>14/07</td>
</tr>
<tr>
<td>Cool Down</td>
<td>Fall 2014</td>
</tr>
</tbody>
</table>
Detector parts

Teflon and Copper parts almost completed:
- Copper cleaning underway

As of August 2012

TeO2 production @ SICCS close to completion

NTD’s: 695 of 1250 already delivered
Critical points in the way of CUORE experiment:
- uniformity of the detector array
- control of possible recontamination during the detector construction

CUORE-0:
- first tower from the CUORE assembly line
- operated as a stand alone experiment in the CUORICINO cryostat

CUORE-0 goals:
- full test and debug of the new CUORE assembly line
  - high statistics check of the improved uniformity of bolometric response
  - identify which operations are critical for the success of CUORE
  - reveal flaws and inefficiencies in the assembly procedures
- thorough exercise of the analysis framework
CUORE0 construction

Mechanical assembly

Sensors & heaters gluing
  • semi-automated system

Sense wire (ball) bonding
  • 50 µm gold wire
  • direct bonding on final detector
Crystal-Sensor coupling

Robotic gluing for
• Uniformly sized
• Repeatable
• Controllable
  glue spots (and coupling)
Mechanical assembly
Cabling
Wire bonding
Storage
CUORE-0 assembly already gave us the opportunity to test and fix the procedures and the systems to realize the CUORE detector: a complete CUORE tower can be assembled in less than 4 weeks.

Other innovative changes (e.g. sense wires) are also being tested.
CUORE-0 status

CUORE-0 is in the pre-operation phase

In August 2012 the detector reached base T of about 8 mK

All the active channels survived the cool-down

CUORE collaboration is not ready to release information on resolution and detector performances but these will come very soon
CUORE-0 status

we already learned that:
• the assembly line works properly
• the thermal contractions didn’t cause problem to the tower wires
• the bonding connections survive to thermal cycles
• the thermal conduction of the new tower wires has to be taken into account for CUORE detector

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CUORE-0 status

Based on CUORE-0 experience, a detailed plan for the 19 CUORE towers has been prepared, aiming at:
- Minimizing manpower, cost, and duration
- Maximizing efficiency
- Preserving quality control

The start of the full plan is expected by the beginning of November.

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We already learned that:
- The assembly line works properly
- The thermal contractions didn’t cause problems to the tower wires
- The bonding connections survive to thermal cycles
- The thermal conduction of the new tower wires has to be taken into account for CUORE detector.
Background: 0.05-0.11 c/keV/kg/y range

If 0.05 c/(keV kg y), expected 2-year sensitivity is
\[ T_{1/2} = 5.9 \times 10^{24} \text{ y} @ 90\%CL \]

(CUORICINO: \( T^{0\nu} > 2.8 \times 10^{24} \text{ y} \))

\[ m_{\beta\beta} = 170-390 \text{ meV} \]

Significance level at which CUORE-0 can observe a DBD signal consistent with the claim in \(^{76}\text{Ge}\) (KK-HK), assuming 0.05 c/keV/kg/y background

- The inner band corresponds to the best-fit value of the claim; the range arises from the “1σ” range of QRPA NME calculations in A. Faessler et al., Phys. Rev. D79 (2009) 053001
- The outer band also includes the 1σ error on the \(^{76}\text{Ge}\) claim

Limited by bkg from cryostat contamination

F.Alessandria et al. [CUORE coll.]
http://arxiv.org/abs/1109.0494v1
The acceptance tests of the 2 vacuum tight chambers (300K and 4K) of the CUORE cryostat have started at the end of May 2012

• The test was completed mid July and the chambers delivered at LNGS by the end of July.

• Since then we are following a detailed plan of commissioning of the cryogenic system which will last for the another 1.5 years

The CUORE vessels @ LNGS (hall B)
Vacuum test @ SIMIC

4k insertion

Cooldown preparation

Superinsulation
Setup commissioning @ LNGS

300K plate

300K & 40K plates

4K plate

Detector suspension system
Commissioning @ LNGS

4K vessel installation

operations under the 300K plate
Conclusions

• With ~200 kg of 130Te and a resolution of 5 KeV FWHM, CUORE has the potential to explore the inverted mass hierarchy of neutrino mixing.

• CUORE-0 has demonstrated that the collaboration can face the challenge of assembling the ~1000 CUORE bolometers (~10 k pieces) in extremely clean conditions.

• CUORE towers assembly will start in a couple of months.

• Cryogenics commissioning was finally started in July 2012. It will continue for the whole 2013.

• CUORE operation will start in 2014.

• CUORE-0 prototype has been successfully installed (in the CUORICINO cryostat) and is presently in the pre-operation phase. It will start to collect data very soon give us answers very soon.