Status of CUORE and Results from CUORICINO

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On behalf of the CUORE Collaboration

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Outline

- Double Beta Decay
  - Process description
  - Scientific content
  - Experimental features
- CUORE & CUORICINO
  - Double Beta Decay with Bolometers
  - CUORICINO: detector description and latest results
  - The CUORE experiment
  - current status of CUORE
Neutrino Open Questions

What we know

➔ Neutrinos have mass
➔ Neutrinos mix
➔ Almost all the Mixing matrix elements have been measured
➔ $\Delta m^2_{SUN}$ and $\Delta m^2_{ATM}$ have been measured

What is still missing

➔ The absolute mass scale
➔ The sign of $\Delta m^2_{ATM}$ (hierarchy)
➔ Whether neutrinos are Dirac or Majorana particles

If lepton number is not conserved, then neutrino is a neutral fermion:

can be described by a Majorana field
Double beta decay is a rare process in which a nucleus changes its atomic number by 2 units

\[ \beta \beta^{2\nu} : (A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu} \]

- Allowed by standard model
- Observed for several isotopes

\[ \beta \beta^{0\nu} : (A, Z) \rightarrow (A, Z + 2) + 2e^- \]

- Forbidden by standard model
- Allowed only for Majorana neutrinos
- Never observed
experiments can measure the decay time $T_{1/2}^{0\nu}$

$$\Gamma^{0\nu} = \frac{1}{T_{1/2}^{0\nu}} = G(Q, Z) \left| M_{NUCL} \right|^2 \left| m_{\beta\beta} \right|^2 = F_N \frac{|m_{\beta\beta}|^2}{m_e^2}$$

**effective Majorana Mass**

$$m_{\beta\beta} = \sum m_i U_{ei}^2$$

Observation of $\beta\beta 0\nu$ would prove that:

- lepton number is not conserved
- neutrinos are Majorana particles

could give informations on the absolute scale of neutrino masses

**Nuclear matrix element** (theoretical uncertainty)

**phase space**

*Strumia, Vissani arXiv:hep-ph/0606054*
Signature:
All the energy is shared between the 2 electrons: **monochromatic line** at the Q-value of the decay

**Sensitivity** $S^{0\nu}$:
decky time corresponding to the minimum number of detectable events above background

$$S^{0\nu} \propto a \cdot \sqrt{\frac{Mt}{b \Delta E}}$$
CUORE and CUORICINO are bolometric detectors for the search of $\beta\beta 0\nu$ decay of $^{130}\text{Te}$

CUORE will search for $\beta\beta 0\nu$ decay in the inverted mass-hierarchy region

CUORICINO is a small prototype of CUORE

- Completed in June 08

Located in the underground Gran Sasso National Labs:
- 3400 w.m.e. shield against cosmic rays
Bolometers

**Principle:** measure the temperature rise of the energy absorber

\[ \Delta T = \frac{E}{C} \]

requires low temperature and low heat capacity

**Thermal bath:** \( \sim 8 \text{ mK} \)

**Absorber**
(dielectric & diamagnetic xtal)

- \( M \sim 790 \text{ g} \)
- \( C \sim 10^{-9} \text{ J/K} \)
- \( \Delta T/E \sim 0.2 \text{ mK/MeV} \)

**Energy release**

**Sensor**
(NTD thermistor)

- \( R \sim 100 \text{ M}\Omega \) (dR/dT)
- \( \text{dR/dT} \sim 100 \text{ k}\Omega/\mu\text{K} \)

**Weak thermal coupling**

**Output signal:** \( \sim 100 \mu\text{V/MeV} \)

1/10/2008
CUORE and CUORICINO use TeO$_2$ crystals: source $\equiv$ detector

decay: $^{130}\text{Te} \rightarrow ^{130}\text{Xe} + 2\text{e}^-$

**why $^{130}\text{Te}$**

- High isotopic abundance: 34%
- No need for enrichment
- Q-value: $\sim 2530$ keV: almost above natural $\gamma$ background

**why TeO$_2$**

- Easy to grow big crystals with low radioactive contaminations
- Good mechanical properties
- Low heat capacity

<table>
<thead>
<tr>
<th>Parent Isotope</th>
<th>$F_N \ [y^{-1}]$</th>
<th>$Q_{\beta\beta} \ [\text{keV}]$</th>
<th>Ab $[%]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{48}\text{Ca}$</td>
<td>$0.54 \cdot 10^{-13}$</td>
<td>4271</td>
<td>0.19</td>
</tr>
<tr>
<td>$^{76}\text{Ge}$</td>
<td>$0.73 \cdot 10^{-13}$</td>
<td>2039</td>
<td>7.8</td>
</tr>
<tr>
<td>$^{82}\text{Se}$</td>
<td>$1.7 \cdot 10^{-13}$</td>
<td>2995</td>
<td>9.0</td>
</tr>
<tr>
<td>$^{100}\text{Mo}$</td>
<td>$5.0 \cdot 10^{-13}$</td>
<td>3034</td>
<td>9.6</td>
</tr>
<tr>
<td>$^{116}\text{Cd}$</td>
<td>$1.3 \cdot 10^{-13}$</td>
<td>2902</td>
<td>7.5</td>
</tr>
<tr>
<td>$^{130}\text{Te}$</td>
<td>$4.2 \cdot 10^{-13}$</td>
<td>2530</td>
<td>34.</td>
</tr>
<tr>
<td>$^{136}\text{Xe}$</td>
<td>$0.28 \cdot 10^{-13}$</td>
<td>2479</td>
<td>8.9</td>
</tr>
<tr>
<td>$^{150}\text{Nd}$</td>
<td>$57. \cdot 10^{-13}$</td>
<td>3367</td>
<td>5.6</td>
</tr>
</tbody>
</table>
Detector: a tower of 62 TeO$_2$ crystals
Mass: 42 Kg (11.8 Kg in $^{130}$Te)

11 floors made of 4 crystals
- not enriched
- Mass: 790g
- Dimensions: 5x5x5 cm$^3$

2 floors made of 9 crystals:
- Mass: 330g
- Dim: 3x3x6 cm$^3$
- 2 enriched in $^{128}$Te (82%)
- 2 enriched in $^{130}$Te (75%)

Internal:
- 1cm low activity Pb
  (A < 4 mBq/Kg in $^{210}$Pb)

External:
- 20cm Pb
- 20cm Borated Polyethylene
- Anti-Rn box: Nitrogen overpressure

Dilution refrigerator
(Coldest point ~ 8mK)
CUORICINO Calibration

3 days every 1 month: $^{232}$Th source

Sum calibration spectra
5 x 5 x 5 crystals

Average resolution: $\sim 8$ keV @ 2615 keV
CUORICINO Results

Statistics
$M \cdot t = 15.53 \text{ kg} \cdot \text{y in } ^{130}\text{Te}$
(up to August 07)

Background
0.18 counts/keV/kg/yr

No signal found

$T_{1/2}^{0\nu} > 3.1 \cdot 10^{24} \gamma @90\% \text{ C.L.}$


$|m_{\beta\beta}| < 0.20 \div 0.68 \text{ eV}$

CUORE

Cryogenic Underground Observatory for Rare Events

Total mass: 741 Kg

$^{130}$Te: 203 Kg

- 988 TeO$_2$ crystals
- 19 towers
- 13 floors
- 52 crystals each

80cm
Expected CUORE sensitivity
in 5 years

Background 0.01 c/keV/Kg/y

\[ T_{1/2}^{0\gamma} > 2.1 \cdot 10^{26} \text{ y @ 90 C.L.} \]

\[ m_{\beta\beta} < 20 \div 100 \text{ meV} \]
Background contributions

- $^{60}$Co from Cu cosmogenic activation: negligible
- Multi-Compton from $^{208}$Tl ($^{232}$Th cont. in cryostat shields): $\sim$40%
- Degraded $\alpha$ from crystal surfaces: $\sim$10%
- Degraded $\alpha$ from Cu holders surfaces: $\sim$50%
- Muon-induced background: negligible
CUORE Background

Tests in HALL C R&D facility
- reduction by a factor ~4 on Crystal surf. contaminations
- Reduction by a factor ~2 on Cu frames surf. contaminations

Projection to CUORE
(goal: $10^{-2}$ c/keV/kg/y)

<table>
<thead>
<tr>
<th>Component</th>
<th>Bkg in DBD region [10^{-2} c/keV/kg/y]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental $\gamma$</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Apparatus $\gamma$</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Crystal bulk</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Crystal surface</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>Cu frames bulk</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Cu frames surface</td>
<td>$\sim 2 \div 4$</td>
</tr>
<tr>
<td>Neutrons</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Muons</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>
The Three Towers Test

Test the best Cu cleaning procedure
➔ Few months data taking, start in Nov 08
➔ Use CUORICINO cryostat

Legnaro Cleaning: TECM
Tumbling
Electropolishing
Chemical etching
Magnetron sputtering

LNGS Cleaning
Electropolishing
Chemical etching
Passivation

Alternative LNGS Cleaning
Electropolishing
Chemical etching
Passivation
Cu frames covered with 50 μm PET foil
CUORE-0
The first tower of CUORE will be assembled and operated in 2009:

- Test “zero-contact” assembling approach
- Same mechanical design as CUORE towers
- Will be hosted in CUORICINO cryostat

CUORE
- Hut construction started @LNGS
- Crystal production started
  First batch will arrive in November 08
- Diluision refrigerator is being built

Data taking is foreseen in 2012
Conclusions

- Observation of $\beta\beta 0\nu$ decay would prove that neutrinos are Majorana particles
- Bolometers are a powerful technique for the search of Double Beta Decay
- CUORICINO has demonstrated the feasibility of CUORE and has set a limit on the $\beta\beta 0\nu$ decay time of $^{130}\text{Te}$
- CUORE construction has started: data taking is foreseen in 2012