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
**ββ0ν Decay Time**

Experiments can measure the decay time $T^{0\nu}_{1/2}$

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

**Phase space**

**Nuclear matrix element**

*Theoretical uncertainty*

Effective Majorana Mass

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

Observation of ββ0ν would prove that:

- Lepton number is not conserved
- Neutrinos are Majorana particles

Could give informations on the absolute scale of neutrino masses

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

$S^{0\nu} \propto a \cdot \sqrt{\frac{M_t}{b \Delta E}}$

- isotopic abundance
- detector mass
- live time
- background counts
- energy resolution
CUORE and CUORICINO are bolometric detectors for the search of $\beta\beta$0v decay of $^{130}$Te

CUORE will search for $\beta\beta$0v 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 m.w.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

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

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

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

**Weak thermal coupling** (\( G \))

**Graph:**

- \( \tau \sim C/G \)

- **Time [s]**: 0, 1, 2, 3, 4, 5

- **Amplitude [a.u.]**: 0, 0.2, 0.4, 0.6, 0.8, 1

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>$Q_{\beta\beta}$ [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>
CUORICINO

Dilution refrigerator
(Coldest point ~ 8mK)

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

Shielding

1/10/2008
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CUORICINO Calibration

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

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

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

Background
0.18 counts/keV/kg/yr

No signal found

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

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

80 cm
Expected CUORE sensitivity in 5 years

Background 0.01 c/keV/Kg/y

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

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

- $^{60}$Co from 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 \(\sim 4\) on Crystal surf. contaminations
- Reduction by a factor \(\sim 2\) 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><strong>Cu frames surface</strong></td>
<td>(~ 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 Status

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
- Dilution 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