A Cryogenic Underground Observatory for Rare Events, CUORE

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on behalf of the CUORE collaboration
Neutrino physics

known

- Neutrinos oscillate ➞ non zero mass
- Some mixing parameters are known

unknown

- Neutrinos mass hierarchy
- Absolute mass scale
- $\nu_e \equiv \bar{\nu}_e$ or $\nu_e \neq \bar{\nu}_e$
The answer to all the previous questions is **neutrinoless double beta decay**

\[ \nu_e \equiv \bar{\nu}_e \]

- Rare event
- Half-life \( > 10^{24-25} \text{ y} \)

**Phase space Factor**

\[ (\tau_{1/2}^{0\nu})^{-1} = G^{0\nu} |M^{0\nu}|^2 \frac{|m_{\beta\beta}|^2}{m_e^2} \]

**Effective neutrino mass**

\[ m_{\beta\beta} = \langle m_\nu \rangle = \sum_k \phi_k m_k |U_{ek}|^2 \]
Design of a DBD0v experiment

If DBD0v \exists
=> Monochromatic signature

Sensitivity

\[ S_{0\nu} \propto \varepsilon \frac{i.a. \sqrt{M \cdot T}}{A \sqrt{\Delta E \cdot b}} \]

i.a.: isotopic abundance

A: atomic mass number

M: source mass

T: live time

\Delta E: FWHM in the ROI

b: bkg in the ROI
Design of a DBD0v experiment (2)

- Calorimetric technique
  - Source $\subseteq$ Detector
- Tracking technique
  - Source $\neq$ Detector

- $\approx$ 100% efficiency
- Energetic resolution
- Detection volume
- Topology

Diagram:
- Source $\rightarrow$ Detector $\rightarrow$ Source
- Source $\rightarrow$ Detector $\rightarrow$ Source
- Detector $\rightarrow$ Source $\rightarrow$ Detector
- Source $\rightarrow$ Detector $\rightarrow$ Source
Bolometric Technique


Source/Detector

\[ C \approx 2 \text{ nJ/K} \approx 1 \text{ MeV/100 } \mu \text{K} \rightarrow 1 \text{mV} \leftrightarrow 1 \text{MeV} \]

Thermometer

NTD Ge-thermistor

\[ R \approx 100 \text{ M}\Omega \]
\[ \frac{dR}{dT} \approx 0.1 \text{ M}\Omega/\mu\text{K} \]

Thermal coupling

\[ G \approx 4 \text{ nW/K} = 4 \text{ pW/mK} \]

TeO₂ \(\rightarrow\) Source/Detector

Ge-NTD \(\rightarrow\) Thermometer

Copper \(\rightarrow\) Heat bath

Ge-NTD gold wires \(\rightarrow\) Thermal coupling
CUORE & Cuoricino use the bolometric technique to search for DBDOv in $^{130}$Te

CUORE will be able to span low neutrino mass region (~meV)

Cuoricino was a small CUORE prototype, about 5 years of data taking starting in 2003

Experiments located underground @ Laboratori nazionali del Gran Sasso

- @ 3400 m.w.e.
- Muon flux: $(3.2 \pm 0.2) \times 10^{-8}$ µ/s/cm²
- Neutron flux: $10^{-6} - 10^{-7}$ n/s/cm²
- Gamma flux $>$3 MeV: 0.73 γ/s/cm²
CUORE & Cuoricino (2)

CUORE & Cuoricino use TeO₂ crystals

DBDOv signal
Excess of events @ $Q_{\beta\beta} = 2527$ keV for $^{130}$Te

$$S_{0,\gamma} \propto \varepsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}}$$

![Graph showing environmental γ bkg spectrum]
**Cuoricino detector**

Cuoricino: 11 modules x 4 crystals (790 g)  
+ 2 modules x 9 crystals (340 g)  

= 11.6 kg of $^{130}\text{Te}$ $\Leftrightarrow$ $5 \times 10^{25}$ nuclei

- 2 enriched crystals @ 75% $^{130}\text{Te}$  
- 2 enriched crystals @ 82.3% $^{128}\text{Te}$
Cuoricino results

Background sources:
- $^{208}$Tl multi-Compton (cryostat): ~ 40%
- U/Th surface contaminations of Cu: ~ 50%
- U/Th surface contaminations of crystals: ~ 50%

Total exposure: 19.75 kg\*y of $^{130}$Te

$T^{0v}_{1/2} > 2.8 \times 10^{24}$ y @ 90% C.L.

$m_{\beta\beta} \leq 0.3 - 0.7^{1-4}$ eV
**Cuoricino results**

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1 Šimkovic 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
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Main concepts:

• Bigger mass: ~x20 Cuoricino
• Heavier shieldings
• Live time x5 longer than Cuoricino
• Better resolution x1.5
• Tightly packed array with a high efficiency in background rejection:
  • n background x30 better
  • µ background x20 better
  • crystals surface contaminations x4 better
CUORE (2)

Cryogenic Underground Observatory for Rare Events

19 towers * 13 modules * 4 crystals = 741 kg TeO₂

203 kg of $^{130}$Te (i.a. 34%) ~ $10^{27}$ nuclei

- better surface treatment
- heavier shieldings
- custom dilution refrigerator

988 crystals
Cuoricino & CUORE prospects

Cuoricino
bkg @DBD0ν
0.18 c/keV/kg/y

$\mathbf{m}_{\beta\beta} < 0.3 - 0.7$ eV

CUORE baseline
bkg @DBD0ν
0.01 c/keV/kg/y

$\mathbf{m}_{\beta\beta} < 35 - 82$ meV

CUORE optimistic
bkg @DBD0ν
0.001 c/keV/kg/y

$\mathbf{m}_{\beta\beta} < 20 - 47$ meV
CUORE cryostat requirements

- Detector base temperature > 10 mK
- Volume to be cooled down 1 m³
- High cooling power because of high thermal load (about 2600 wires run from 10 mK to 300 K)
- Anti-vibration system
- Bigger shieldings
- Employment of radio-pure materials
- Long measurement time (10 y)
  - Stable
  - Service-free
  - High duty cycle running
  - Cryogen-free Dilution Unit
CUORE cryostat construction

- Pulse tube (x5)
- Suspension support
- 300 K SS flange (OVC)
- 40 K OFE copper flange
- 4 K SS flange (IVC)
- Lead shields (1.7 t + 5.4 t) @ still temperature
- Mixing chamber
- Lead shield @ 50 mk (2.7 t, 30 cm thick)
- CUORE detector @ 10 mK (1.5 t)
Refrigerators

- Diluition Refrigerator:
  - DRS-CF-2000 (Leiden Cryogenics)
  - $P = 5 \mu W (>1.5 \times 10^3 \mu W) @ 12 \text{ mK (120 mK)}$

- x5 Cryomech Pulse Tube 415
  - Two Stage (300 K $\Rightarrow$ 77 K; 77 K $\Rightarrow$ 4 K)
  - $P = 1.5 \text{ W (40W)} @ 4.5 \text{ K (44 K)}$
Conclusions

• Cuoricino’s performance demonstrates the feasibility of a large scale bolometric detector.

• Cuoricino set a lower limit on DBDOv half-life of $T^{0v}_{1/2} > 2.8 \times 10^{24}$ y @ 90% C.L.

• CUORE is a second generation Neutrinoless Double Beta Decay experiment currently under construction.

• CUORE cryostat is the first attempt ever done of cool a mass as large as 1500 kg down to 10 mK (+ tons of shieldings to mK scale).

• CUORE data taking is forseen in 2013.
CUORE calibration system

- 12 $\gamma$ sources
- Kevlar string from 300 K to detector
- radioactive capsules crimped to the string
- thermalization mechanism

Source locations

- Thoriated Tungsten wire
- Kevlar string
- Teflon cover
- Source capsule

Top view of detector array with source positions

Lead shield

Guide tubes

Detectors