Cryogenic search for neutrinoless double beta decay

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on behalf of the CUORE collaboration
Motivation – $0\nu\beta\beta$

• $0\nu\beta\beta$ is only experimentally feasible way to distinguish Dirac vs. Majorana neutrinos

\[\nu \neq \bar{\nu}\]

• if $0\nu\beta\beta$ observed:
  • lepton number violation
    \[\Delta L = 2\]
  • Schechter-Valle theorem
    \[\nu = \bar{\nu}\]
  • hint for seesaw type 1
    \[m_\nu = m_D^2 / M_R << m_D\]
  • possible to determine absolute neutrino mass scale and hierarchy

\[\langle m_{\beta\beta} \rangle = \left| \sum_{i=1}^{N} \lambda_i |U_{ei}|^2 m_i \right|\]

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Bolometric Approach

• several techniques employed to search for 0νββ

• here: bolometric approach
  • all energy measured in form of heat
  • source = detector
  • several isotopes can be used
  • large masses
  • no event topology

typical pulse shape parameters for large bolometers:
  • rise time: ~ 50 ms
  • decay constant: ~ 200 ms
  • total pulse length several seconds
  • pulse shapes help identifying fake signals, e.g. electronics noise
CUORE Experiment

**CUORE Experiment**

**LNGS**

- **Cryogenic Underground Observatory for Rare Events**
- located in Hall A of Gran Sasso National Lab (LNGS)

- overburden of ~3100 m.w.e. (relative to flat overburden) *Phys. Rev. D73 053004*

- array of 988 bolometers
  - 19 towers, 13 planes
  - 4 bolometers/plane/tower

- total detector mass 741 kg
  - $M(^{130}\text{Te}) \sim 200 \text{ kg}$ ($^{130}\text{Te}: 0\nu\beta\beta$ candidate isotope)

- it is all about reducing background:
  - Borated polyethylene neutron shield
  - at least 36 cm lead shields
  - only radiopure material copper, teflon
  - goal: reach a flat bkg of $0.01 \text{ cts/(keV kg y)}$ in ROI
    - demonstrated within factor 2 - 4

- cryogen-free dilution refrigerator

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CUORE Bolometers

- large bolometers 5 x 5 x 5 cm
- made from natural TeO$_2$
- $^{130}$Te abundance $\sim 34\%$ (no enrichment)
- Q-value ($^{130}$Te) = 2528 keV

Temperature sensor:

- NTD Ge thermistor

\[ R(T) = R_0 e^{\sqrt{T_0 / T}} \]

- resistance change converted into voltage pulse
- non-linear energy response

Resolution:

- FWHM $\sim 5$ keV @2528 keV

Phys. Rev. C 80 025501
Phys. Rev. Lett. 102, 212502


CUORE Calibration System  see also poster 123 by Ian Guinn

- calibration is big challenge
  - slow detector response requires low activity sources (~100mBq)
  - large shielding & good self shielding requires sources inside detector array
  - for bkg reasons sources have to be stored outside the cryostat

- 12 source strings move under own weight 300K to 10mK without shifting detector base temperature

- each string has 30 copper crimps housing $^{232}$Th wire, calibrating 500keV - 3000keV

- heat load requirements very strict: sources need to be at 4K

- dedicated thermalization mechanism currently tested
Cuoricino

• predecessor of CUORE using same experimental technique
  • located at LNGS Hall A  smaller cryostat, single tower
    44 crystals: 5cm x 5cm x 5cm (CUORE-type)  FWHM ~6 keV
    18 crystals: 3cm x 3cm x 6cm  FWHM ~10 keV
    4 are enriched  FWHM ~14 keV
  • \( M(\text{Te}^0_2) = 40.7 \text{ kg} \Rightarrow \text{Te}^{130} = 11.3 \text{ kg} \)
  • Total exposure 19.75 kg • y
• two independent analyses, US and Italy:
  (very similar, agreeing, results)
  • \( b(\text{ROI}) = 0.169 \pm 0.01 \text{ cts} / (\text{keV kg y}) \)
  • \( T^{0\nu}_{1/2} (\text{Te}^{130}) > 2.8 \times 10^{24} \text{ y} \ (90\% \ C.L.) \)
    (presented @ Neutrino 2010)
  • \( m_{\beta\beta} < 300 -700 \text{ meV} \) (depending on choice of NME)
• Cryostat will be further used for CUORE-like tower assembly tests: CUORE-0

\( 0\nu\beta\beta \) expected
CUORE Experiment - Status

now:
• CUORE experimental hut finished
• cryostat main support in place
• 450 bolometers ready and stored underground at LNGS; tests ongoing
• US bolometer production started

• 12/2010 outer cryostat vessels delivery
• 12/2010 partial calibration system delivery
• early 2011 cryostat 4K tests
• mid 2011 delivery dilution unit
• fall 2011 CUORE-0 data taking
• 2013 CUORE data taking
Projected Sensitivity

- 5 years live time and bkg of \( b = 0.01 \) cts/ (keV kg y)

**CUORE Sensitivity at 1\( \sigma \):**

\[ T^{0\nu}_{1/2} = 1.5 \times 10^{26} \text{ y at 1}\( \sigma \) \]

**\( m_{\beta\beta} \) = 41 – 96 meV**

(depending on NME)

- start probing inverted hierarchy
Summary

- $0\nu\beta\beta$ is only experimentally feasible way to distinguish Dirac vs. Majorana neutrinos

- CUORE uses bolometers made of natural TeO$_2$ to search for $0\nu\beta\beta$ of $^{130}$Te

- Goal of background in ROI of 0.01 cts/(keV kg y); demonstrated within factor 2-4

- Calibration is challenging: 12 strings with 30 sources brought into cryostat from 300K to 10mK, without changing detector base temperature

- Good progress being made:
  - CUORE-0 data-taking starts fall 2011
  - CUORE data-taking 2013

- CUORE sensitivity at $1\sigma$ $T_{1/2}^{0\nu} = 1.5 \times 10^{26}$ y $\Rightarrow m_{\beta\beta} = 41$-96 meV start probing inverted hierarchy