CUORE- Cryogenic Underground Observatory for Rare Events

- Could be the most sensitive search for zero-neutrino double-beta decay.
- The technique is proven by CUORICINO
- The best discovery potential
- Isotopic enrichment highly desirable but not absolutely necessary (33.8% nat. ab.)
- US Costs ~ 1/10 of that of the only comparable experiment.
- To make this experiment optimal, this should be a real Italy/US cooperation: INFN/NSF/DOE

Parameters of $T^{0\nu}_{1/2}$ Sensitivity

$$T^{0\nu}_{1/2} \simeq \frac{ln2Nt\epsilon}{\gamma\sqrt{bMt\,\delta E}}$$

$$T^{0\nu}_{1/2} \simeq \frac{ln2(A_0/W) \times 10^3(Mat\epsilon)}{\gamma\sqrt{bMt\,\delta E}}$$

$$T^{0\nu}_{1/2} \propto \frac{a\epsilon}{W}\sqrt{\frac{Mt}{b\,\delta E}}$$

$a \equiv isotopic\ abundance$

$b \equiv background\ rate\ in\ c/(keV \cdot kg \cdot y)$

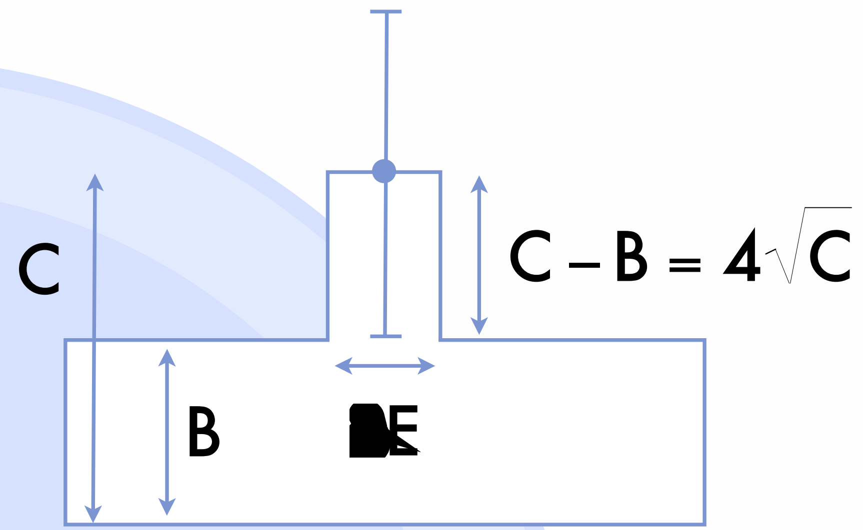
$M \equiv source\ mass$

$\delta E \propto energy\ resolution$

$\epsilon \equiv detection\ efficiency$

$W \equiv molecular\ weight$

Detection with a 4[redacted] CL



$$T^{0\nu}_{1/2} \simeq 4.74 \times 10^{25} \frac{a\epsilon}{W} \sqrt{\frac{Mt}{b\,\delta E}}\ \ y$$

$a \equiv isotopic\ abundance$

$b \equiv background\ rate\ in\ c/(keV \cdot kg \cdot y)$

$M \equiv source\ mass$

$\delta E \propto energy\ resolution$

$\epsilon \equiv detection\ efficiency$

$W \equiv molecular\ weight$

Neutrinoless Double-Beta Decay

Experimental Figure of Merit

$$f \equiv \frac{\overline{\eta} a \epsilon}{W} \sqrt{\frac{M}{b \delta E}}$$

$$\eta \equiv G^{0\nu} |\mathcal{M}^{0\nu}|^2 \times 10^{13} = F_N \times 10^{13}$$

$$\overline{\eta} \equiv \langle \eta \rangle_{nuclear\ models}$$

Available Enriched Isotopes

- ^{48}Ca - AVLIS† (USA)
- ^{76}Ge - Centrifuge (Russia)
- ^{82}Se - Centrifuge (Russia)
- ^{100}Mo - Centrifuge (Russia) & AVLIS† (USA)
- ^{116}Cd - Centrifuge (Russia) & AVLIS† (USA)
- ^{130}Te - Centrifuge (Russia)
- ^{136}Xe - Centrifuge (Russia)
- ^{150}Nd - AVLIS† (USA)

† Technology available at LLNL. No known production program.

Average Theoretical Nuclear Structure Factors

Parent Isotope	$\langle F_N \rangle \equiv \left\langle G^{0\nu} \left| M^{0\nu} \right|^2 \right\rangle \; y^{-1}$
^{48}Ca	$(5.4^{+3.0}_{-1.4}) \times 10^{-14}$
^{76}Ge	$(7.3 \pm 0.6) \times 10^{-14}$
^{82}Se	$(1.7^{+0.4}_{-0.3}) \times 10^{-13}$
^{100}Mo	$(1.0 \pm 0.3) \times 10^{-12}$
^{116}Cd	$(1.3^{+0.7}_{-0.3}) \times 10^{-13}$
^{130}Te	$(4.2 \pm 0.5) \times 10^{-13}$
^{136}Xe	$(2.8 \pm 0.4) \times 10^{-14}$
^{150}Nd	$(5.7^{+1.0}_{-0.7}) \times 10^{-12}$

Table of Values of $\overline{\eta}$

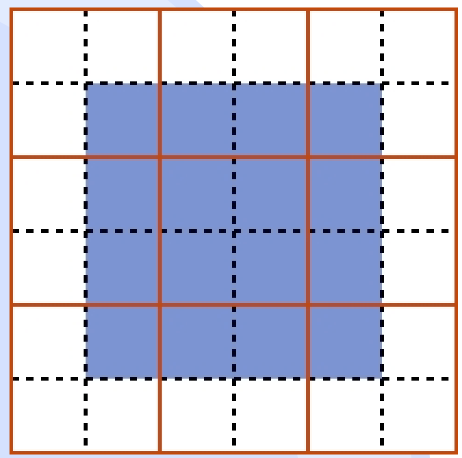
$$\overline{\eta} \equiv \langle G^{0\nu} |\mathcal{M}^{0\nu}|^2 \rangle \times 10^{13}$$

Isotope	$\overline{\eta}$
^{48}Ca	0.54
^{76}Ge	0.73
^{82}Se	1.70
^{100}Mo	10.0
^{116}Cd	1.30
^{130}Te	4.20
^{136}Xe	0.28
^{150}Nd	57.0

Cryogenic Detector

- CUORE/CUORICINO (Gran Sasso)
- 760 kg of TeO_2 (nat. abundance = 33.8%)
- 1000 bolometers at ~ 8 mK
- 25 Towers of 40 bolometers per tower
- CUORICINO ~ 1 tower, operated 03/04
  $T_{1/2}^{0\nu} \geq 7.5\text{x}10^{23}\,y$

One Possible Partially Enriched Version



■	Isotopically Enriched	160 crystals
□	Natural Abundance	240 crystals

Target Half-Lives for $\langle m_{\nu} \rangle = 0.04$ eV

Isotope	$T_{1/2}^{0\nu}$
^{48}Ca	3.0×10^{27}
^{76}Ge	2.3×10^{27}
^{82}Se	9.4×10^{26}
^{100}Mo	1.6×10^{26}
^{116}Cd	1.3×10^{27}
^{130}Te	3.9×10^{26}
^{136}Xe	5.8×10^{27}
^{150}Nd	2.9×10^{25}

$$f = \frac{\overline{\eta} a \epsilon}{W} \sqrt{\frac{M}{b \, \delta E}}$$

	$\overline{\eta}$	a	ϵ	W	M	b	δE	f
Majorana	0.73	0.86	0.70	76	500	3×10^{-3}	3.5	~1.3
CUORE’	4.2	0.54	0.84	162	304	3×10^{-3}	8.0	~1.3
CUORE’’	4.2	0.85	0.84	162	760	3×10^{-3}	8.0	~3.3
EXO	0.28	0.80	0.3?	136	1000	3×10^{-5}	60	~0.4
						3×10^{-6}		~1.2
S-NEMO	1.70	0.90	0.3	114	100	3×10^{-5}	200	~0.5

$$b = keV^{-1} kg^{-1} y^{-1} \qquad \delta E = keV$$

Conclusions

- Large value of $G^{0\nu}|\mathcal{M}^{0\nu}|^2$ (linear) [redacted]
- High Efficiency (linear) ϵ
- High Isotopic Abundance (linear) a
- Large Source Mass $\sqrt{M}$
- Good Energy Resolution $\sqrt{\delta E}$
- Low Background $\sqrt{b}$
- Cost Feasibility $

$$f \equiv \frac{\overline{\eta} a \epsilon}{W} \sqrt{\frac{M}{b\, \delta E}}$$