Search for Neutrinoless Double Beta Decay with CUORE: Status and Prospects

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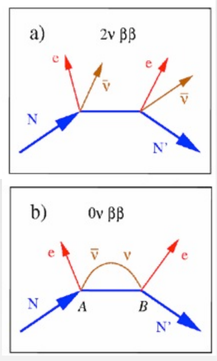
Neutrinoless Double Beta Decay: 0νββ

Are neutrinos Majorana particles?



2ν mode: conventional 2nd order process in nuclear physics

$$\Gamma_{2\nu} = G_{2\nu} \mid M_{2\nu} \mid^2$$

G are phase space factors

0ν mode: hypothetical process only if $M_\nu \neq 0$ AND $\nu = \bar{\nu}$

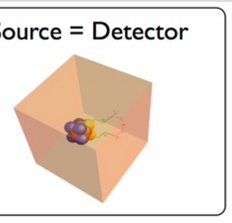
0νββ would imply
- lepton number non-conservation
- Majorana nature of neutrinos

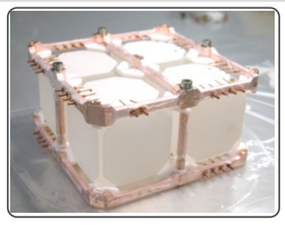
0νββ may allow us to determine
- effective neutrino mass

$$\Gamma_{0\nu} = G_{0\nu} \mid M_{0\nu} \mid^2 \left\langle m_{\beta\beta} \right\rangle^2$$

Experimental Approach

Source = Detector



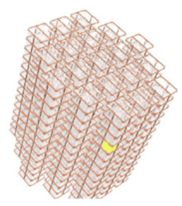


$^{130}Te \rightarrow {}^{130}Xe + 2e^-$ Q = (2527.518 +/- 0.013) keV

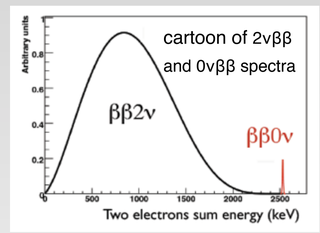
Use as calorimeter to watch for events of energy $E=Q_{\beta\beta}$

The two electrons are fully contained within single source crystal in about 87% of all cases.

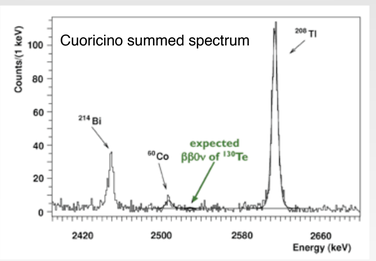
single hit, monochromatic event



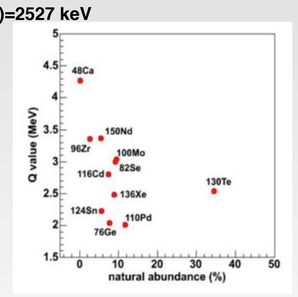
Search for 0νββ in ^{130}Te



Experimental Signature of 0νββ
- peak at the transition Q-value
- enlarged by detector resolution
- over unavoidable 2νββ background



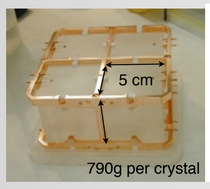
Q(^{130}Te)=2527 keV

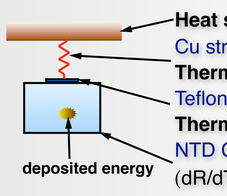


energy = key event signature

High natural abundance, no need for enrichment
Q-value @ 2527 keV is above the energy range of most naturally occurring γ rays

TeO_2 Bolometers





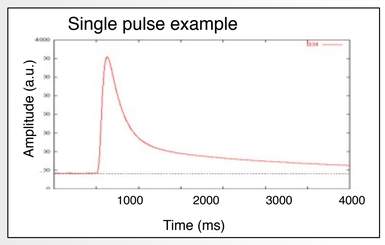
Heat sink: Cu structure (8-10 mK)
Thermal coupling: Teflon (G = 4 pW/mK)
Thermometer: NTD Ge-thermistor (dR/dT ≅ 100 kΩ/μK)
Absorber: TeO_2 crystal (C ≅ 2 nJ/K ≅ 1 MeV / 0.1 mK)

TeO_2 Bolometer: Source = Detector

For E = 1 MeV: ΔT = E/C ≅ 0.1 mK
Signal size: 1 mV
voltage signal ∝ energy deposited

Time constant: τ = C/G = 0.5 s
Energy resolution: ~ 5 keV at 2.5 MeV

Single pulse example

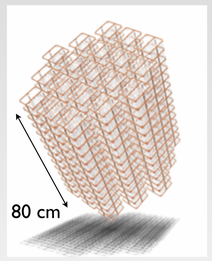


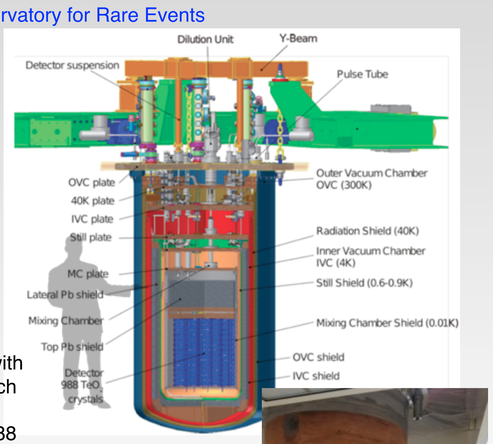
CUORE at LNGS, Italy

1.4-km avg. rock overburden = 3100 m.w.e. flat overburden

factor 10^6 reduction in muon flux to ~ 3×10^{-8} μ/(s cm^2)

CUORE Cryogenic Underground Observatory for Rare Events





19 Cuoricino-like towers with 13 planes of 4 crystals each

a tightly packed array of 988 bolometers with mass of ~ 200 kg of ^{130}Te

- Operate at Gran Sasso laboratory
- Special cryostat built w/ selected materials
- Cryogen-free dilution refrigerator operated at ~ 10mK
- Shielded by several lead shields

Detector Calibration System

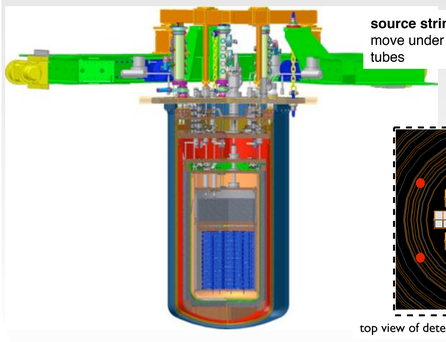
Energy Calibration of 988 Bolometers

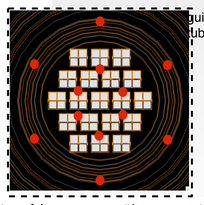
insertion of 12 gamma sources that move under own weight

motion system: insertion and extraction of sources in and out of cryostat

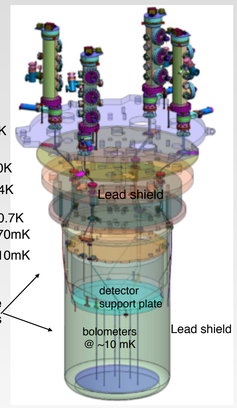
guide tubes: no straight vertical access

source strings: move under own weight in guide tubes





top view of detector array with source positions



Crystal Production

CUORE TeO_2 crystal production started at SICCAS in Jiadeng in 2008

- 30 crystals/month (shipped by sea to minimize cosmogenic activation)

- 888 crystals at LNGS

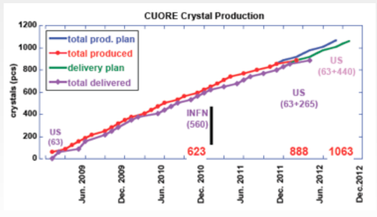
- complete production and delivery by end of 2012

4% of the crystals tested in CCVR runs

- check contract specifications

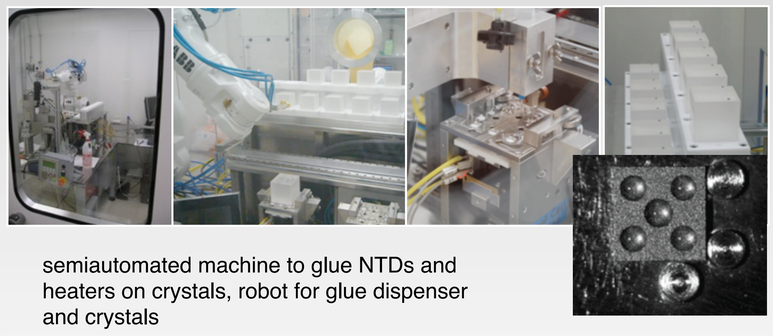
- ICPMS and HPGe checks on Te, TeO2 and chemicals

- FWHM resolution @ 2615 keV (^{208}Tl): 4.6 ± 1.2 keV



CUORE Assembly Line

Gluing



semiautomated machine to glue NTDs and heaters on crystals, robot for glue dispenser and crystals

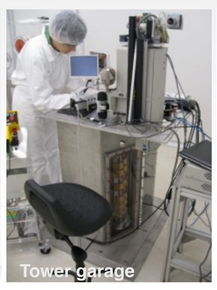
optimization ongoing

production rate: 8-12 crystals/day

CUORE Background Budget

Source	C/keV•kg•yr (ROI)	Method
Crystal surface	< 4 x 10^{-3}	Bolometric test, MC
Mount structure surface	<2 - 3 x 10^{-3}	Bolometric test, MC
xtal cosmogenic activation	1 x 10^{-3}	Bolometric test, MC
Gold wires (U/Th in bulk)	< 1 x 10^{-3}	Bolometric test, MC
Cu frames (Th in bulk)	< 1.5 x 10^{-3}	HPGe, NAA, MC
Roman lead (Th in bulk)	< 4 x 10^{-3}	Bolometric test, HPGe
Muons	< 1.8 x 10^{-3}	Measurement, MC

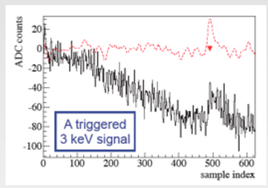
Mechanical Detector Assembly

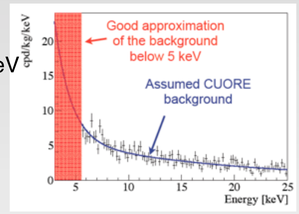


Dark Matter Sensitivity of CUORE

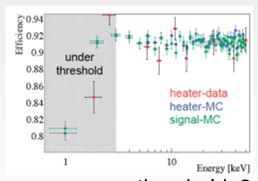
Improved Trigger for DM Search

DM and axion signals: ~ keV
CUORE standard trigger threshold: 20-30 KeV

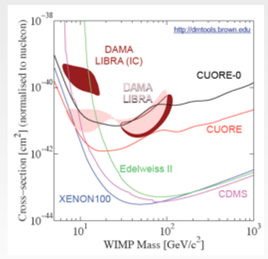




new dedicated trigger developed

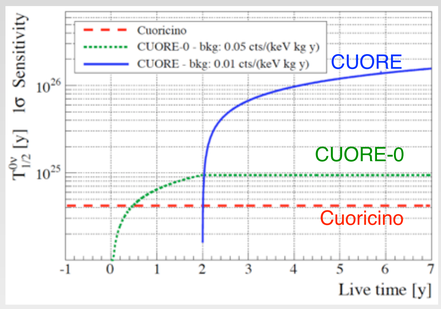


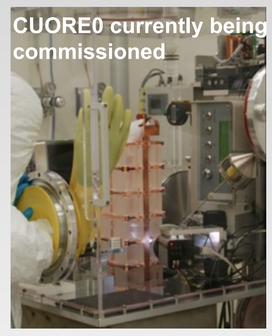
energy threshold: 3 keV
eff above threshold: 90%



Di Domizio, Orio, Vignati, JINST 6, P02007 (2011)).

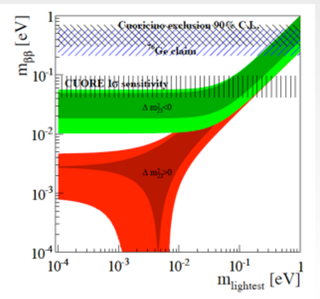
CUORE-0 and CUORE Sensitivity





CUORE-0 (2012-2014)
single CUORE tower
<$m_{\beta\beta}$> < 170-350 meV (1σ)
Currently Being Commissioned

CUORE (2014 - ....)
<$m_{\beta\beta}$> < 47-87 meV (1σ)



images and figures: courtesy of CUORE collaboration