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Sensitivity to double beta decay of ^{130}Te to the first 0^+ excited state of ^{130}Xe in CUORE

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Abstract. We report a preliminary result on the sensitivity and analysis techniques to search for double beta decay of ^{130}Te to the first 0^+ excited state of ^{130}Xe in CUORE. With a TeO_2 exposure of 369.9 kg · y, we find an expected limit setting sensitivity of $T^{0\nu}_{1/2} > 3 \cdot 10^{24}$ y at 90 % C.I. .

1. Introduction

CUORE is a ton-scale cryogenic bolometer array of 988 TeO_2 cubic crystals operated underground at the Laboratori Nazionali del Gran Sasso (LNGS) of INFN, with the main aim of searching for the neutrinoless double beta decay ($0\nu\beta\beta$) of ^{130}Te and other rare processes [1]. The energy released by particle interactions in the crystals causes a temperature rise. Neutron Transmutation Doped Ge thermistors transform the temperature pulses into voltage pulses which are low-pass filtered, amplified and continuously digitized (see [2] for further details).

The most sensitive search for $0\nu\beta\beta$ is performed in the gs-gs[1] transition, nevertheless an independent search for $0\nu\beta\beta$ can be performed in the gs-es[2]. In addition the 2-neutrino double beta decay ($2\nu\beta\beta$) gs-es transition, predicted by the Standard Model, has not yet been observed in ^{130}Te. A measurement of the half life of this process could provide useful informations to improve and validate the nuclear matrix element computation methods.

2. Results

The gs-es transition has a Q value $Q^* = 734\,\text{keV}$ [3], smaller than the gs-gs one. The daughter nucleus de-excitation can follow 3 different paths with different gamma emissions:

- Pattern A (86.0 %): $E^A_{\gamma 1} = 1257.41\,\text{keV}$ $E^A_{\gamma 2} = 536.09\,\text{keV}$
- Pattern B (12.2 %): $E^B_{\gamma 1} = 671.35\,\text{keV}$ $E^B_{\gamma 2} = 586.06\,\text{keV}$ $E^B_{\gamma 3} = 536.09\,\text{keV}$
- Pattern C (1.8 %): $E^C_{\gamma 1} = 1122.15\,\text{keV}$ $E^C_{\gamma 2} = 671.35\,\text{keV}$

The presence of de-excitation gammas emitted in coincidence with the 2 electrons allows a clean tagging of the events and eases the background rejection. We define *multiplicity* the number of coincident (within a time window of ±30 ms) crystals that reconstruct an energy

[1] Ground state to ground state transition, referring to the 0^+ gs of ^{130}Te and the 0^+ gs of ^{130}Xe.
[2] Ground state to excited state transition.

ID	Energy [keV]	Energy [keV]	Energy [keV]	Energy [keV]
2A0 - 2B1	**1270**	1257		
2A1-2B2-2C1	1794	**734**		
2A2-2B3	**1991**	536		
3A0	1257	**734**	536	
2B0 - 2C0	**1856**	671		
2B4	**1320**	1207		
2B5	**1941**	586		
2B6 - 2C0	**1405**	1122		
3B0	**1270**	671	586	
3B1-3C0	1122	**734**	671	
3B2	1257	**734**	536	
3B3	**1320**	671	536	
3B4	1207	**734**	586	
3B5	**1405**	586	536	
4B0	**734**	671	586	536

Table 1. All the considered experimental signatures for a gs-es transition are listed. In the first column an identifier string of the form MSX is present, where M is the multiplicity, S represents the originating de-excitation pattern, X is an integer index. Each other column represents the expected energy release in a bolometer. Bold entries highlight the channel where the $\beta\beta$ energy release is expected. For $2\nu\beta\beta$ the endpoint energy of the $\beta\beta$ spectrum is reported. Some scenarios have more than one identifier because they can be originated by multiple different de-excitation patterns.

release above a given threshold $E_{th} = 80\,\mathrm{keV}$. Requiring the energy of each final state particle to be fully contained in one crystal defines a finite set of possible combinations of energy releases (signature) involving up to four crystals (see Table 1). For both the $0\nu\beta\beta$ and the $2\nu\beta\beta$ channels a monochromatic peak is expected in (at least) one of the involved crystals ultimately reducing the analysis to the search of the peak associated with each signature. To further simplify the procedure, a ranking of the signatures is performed. The Monte Carlo (MC) simulations of the CUORE background sources allow to predict, for each signature, the expected background counts for the current available exposure of $369.9\,\mathrm{kg}\cdot\mathrm{y}$. The signal selection efficiency can be computed from MC simulations as well. It is finally possible to compute a normalized score function for each signature[3]

$$\hat{S}_i \doteq \frac{S_i}{\sum_j S_j} \quad \text{where} \quad S_i \doteq \frac{\epsilon_i}{\sqrt{B_i}} \tag{1}$$

ϵ_i is the signal selection efficiency for the i-th signature and B_i is the expected number of background counts. Only the signature with the highest ranking is considered. We find that the selected signature has a normalized score $> 50\,\%$. The signature corresponds to a multiplicity 3 detection of the de-excitation pattern A of gamma emission (one crystal hosts the $\beta\beta$ energy release). Since the $0\nu\beta\beta$ decay has a monochromatic beta emission while the $2\nu\beta\beta$ emits a continuous spectrum up to Q^*, the expected background in the $0\nu\beta\beta$ signature is much lower because the selected energy range is smaller, allowing for a background free search. The selection efficiency of the considered signature is $\epsilon_{sel} = (2.67 \pm 0.03_{\mathrm{stat}})\%$ and constitutes the dominant contribution. A further correction to take into account the trigger, pile-up[4] and anti-

[3] Events were selected in a symmetric 10 keV wide region around the expected energy releases.
[4] A pile-up event is defined as two thermal pulses occurring in the same detector within $< 10\,\mathrm{s}$ from each other.

coincidence efficiency is applied. We find that the expected limit setting sensitivity at 90 % C.L. is $T^{0\nu}_{1/2} > 3 \cdot 10^{24}$ y.

The computation of the sensitivity to the $2\nu\beta\beta$ gs-es transition cannot be performed analytically since the signature is not expected to be background free. Work is in progress to evaluate it.

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